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IGC Newsletter

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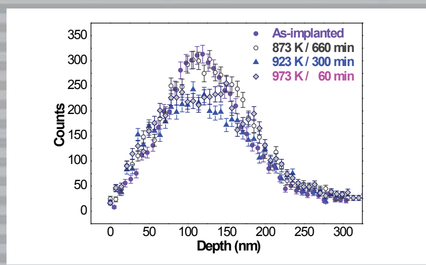

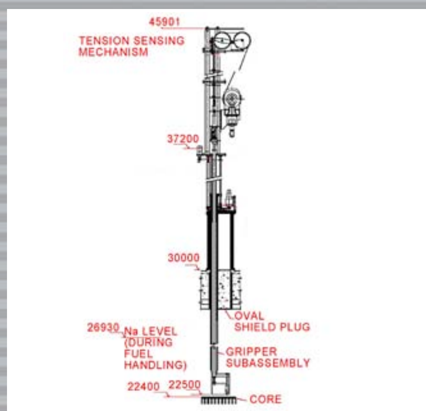

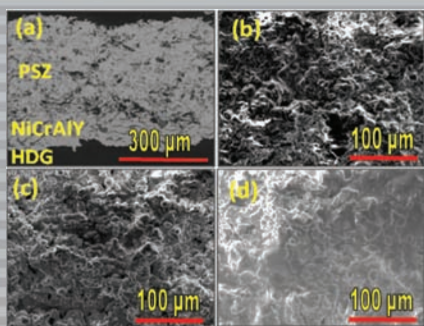

INDIRA GANDHI CENTRE FOR ATOMIC RESEARCH
http://www.igcar.gov.in/lis/nl96/igc96.pdf

From the Editor

Dear Reader

I am happy to forward a copy of the latest issue of IGC Newsletter (Volume 96, April 2013 issue).

This is the first issue being brought out after Dr. P. R. Vasudeva Rao has taken over as Director, IGCAR.

In the Director's Desk, Dr. P. R. Vasudeva Rao, Director, IGCAR has given an overview of the challenges in various disciplines that our Centre is pursuing towards achieving leadership in Fast Breeder Reactors and associated Fuel Cycle Technologies.

We have introduced a new feature in the Newsletter, the interview of an eminent person by a team of young officers. In this issue we have had the privilege of Shri S. C. Chetal, Former Director, IGCAR, sharing his experiences with young colleagues.

In one of the technical articles Dr. K. Ananthasivan has described the direct measurement of the solidus temperature of mixed carbide fuel (Mark I) of FBTR using a new experimental facility that has been setup at our Centre.

In the second technical article, Shri Christopher David gives an account of the studies on the interaction of implanted nitrogen with irradiation induced defects in D9 steels and diffusion behaviour of silicon in D9 steels.

In the Young Officer's forum, Shri N. Subramanian has shared his experience in the design of instrumentation and control system for sodium testing of fuel handling machines.

In the Young Researcher's forum Shri Jagadeesh Sure has detailed the investigation on the performance of yttria stabilized zirconia and alumina-titania coatings on carbon materials such as high density graphite, towards deploying these coated materials for various applications in pyrochemical reprocessing.

This Newsletter carries reports on the "Inauguration of Integrated Facility for Fusion Reactor Materials", "24th Annual General Meeting of the Materials Research Society of India" and "9th CEA-IGCAR Annual Meeting on Liquid Metal Fast Reactor Safety".

Delegation from Czech Republic and ASEAN countries, and Dr. S. Sivaram from National Chemical Laboratory, Pune 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. Sai Baba)
Chairman, Editorial Committee, IGC Newsletter
&
Associate Director, Resources Management Group

Our New Director

Shri S. C. Chetal greets Dr. P. R. Vasudeva Rao on his assumption of charge as Director, IGCAR

Dr. P. R. Vasudeva Rao, Distinguished Scientist and Director, Chemistry Group has taken over as Director, Indira Gandhi Centre for Atomic Research, with effect from February 1, 2013

Director's Desk

I am pleased to address you through this column of IGC newsletter, having taken over as the Director of this prestigious institution from 1st February this year.

IGCAR is a premier R&D unit of the DAE, unique with respect to its mission, its facilities and work culture. It has consistently met all the technological challenges posed to it and made an impact in the international fast reactor community. The Centre has reached this position of preeminence, thanks to the visionary leadership that was provided by successive Directors of the Centre, starting from Shri N.Srinivasan. It is indeed a matter of pride as well as a great responsibility for me to preside over this great institution.

Having established and operated the FBTR successfully, IGCAR is today working very closely with BHAVINI towards the construction and commissioning of the PFBR project. We are simultaneously working on R&D aspects that would further enhance the safety and economics of future fast reactor systems. The development of metallic alloy fuelled fast reactors with high breeding ratio, as a means to enhance the growth of fast reactors, is an assignment that is being addressed by several groups in the Centre. The closing of the fast reactor fuel cycle through fuel reprocessing and refabrication, is being pursued at the same time, to ensure sustainability of the fast reactor programme. The facilities, knowledge base and expertise in a variety of domains including sodium technology, materials, chemistry, safety, structural mechanics, electronics and instrumentation, inspection technologies etc., and the extensive collaborations and proactive human resource policy have made IGCAR an institution of international repute.

Today, we can be proud of the contributions that we have made to the PFBR project that would launch the fast reactors onto commercial domain and we would continue to provide all necessary support to the project in its commissioning and operational stages. This step is crucial for the three stage power programme of the Department and the world-wide nuclear community is looking up towards us for this breakthrough in fast reactor technology development. The forthcoming months will see the delivery of the remaining components of PFBR for which IGCAR is responsible for the manufacturing technology development and we also hope to launch the construction of the fast reactor fuel cycle facility later this year.

However, we do face a number of technological challenges ahead in our journey. This is especially the case with fast reactor fuel cycle, which needs to be established on a commercial scale meeting all the requirements of safety and at the same time delivering the products with economical operations. The continued safe operation of FBTR for an extended life period would be essential for our programmes, and necessary efforts and investments are being made towards extending its life and ensuring its robust operation. Post-Fukushima, the emphasis on maintaining reactor safety even in the event of a total station black out has become an important issue. Sodium safety is another topic which will continue to engage our attention, so also will be the development of robust and passive shut down systems that will ensure reactor safety. In addition, we need to address a whole gamut of issues related to the materials performance, inspection technologies, sensors instrumentation, etc. Other challenges include recovery and burning of minor actinides, development of pyrochemical reprocessing schemes and remote refabrication of the fuels. We will also continue our emphasis on basic research as a tool to obtain new insights into materials and processes, and harness the advances for the benefit of the fast reactor programme. We also have opportunities to make significant contributions to the ITER programme and other energy systems. Fortifying the infrastructure and human resource development are other areas that will continue to engage our attention. There is also an urgent need to enhance our academic collaborations and tap the excellence that prevails in many R&D and educational institutions for the benefit of our programme.

Our Centre is blessed with outstanding and committed leaders at various levels, and we can have the confidence of meeting our objectives, setting international benchmarks for excellence and innovation in the process.

It has been my privilege to have been associated with the newsletter from its inception. While the newsletter serves the purpose of disseminating the recent developments at our Centre, we would make additional efforts to bring out documents that deal with specific issues that concern the common man with respect to nuclear energy in general and fast reactors in particular (examples: safe handling of sodium, severe accident management..).

When this issue was being finalized, we received the sad news of the demise of Shri S.R.Paranjpe, former director of IGCAR. He was a strong proponent of fast reactors and provided visionary guidance to the programme in its formative stages. A detailed profile of Shri Paranjpe appears elsewhere in the issue. The best way that we can honour his memory is to rededicate ourselves to delivering the fast reactor technology to the country in an expeditious manner .

I welcome and look forward to suggestions and comments from enlightened readers on various issues related to programmes of the Centre.

P. R. Vasudeva Rao
Director, IGCAR

Interaction with Eminent Colleagues

Shri S.C. Chetal interacting with the young officers

Sir, you have worked for 42 years in DAE, after achieving so much, how do you still find the motivation and drive to continue?

I always presume that the knowledge acquired by me is comparable to a drop and the areas in which I am still unfamiliar are comparable to a ocean. Hence, I always have a thirst for knowledge and to fulfill the thirst I developed a passion for reading and teaching. I would also say that the knowledge gained by me should be such that " I should find a solution to a problem in the area in which I am familiar on the spot without looking for anything'. For this I keep myself updated and go through the technical literature available with me and read them though I would have read the same in the past. I also enjoy reading technical literature and teaching, in particular, to my grandchildren.

Why did you join DAE and what were your expectations when you first came to IGCAR after BARC training school way back in 1971?

I was the second overall topper from my batch from the training school. Shri S. K. Mehta, the then Head, RED, BARC wanted me to join Hall 3, BARC and work on R&D of reactor systems, but my enthusiasm at that tender age was to work on a new project from the scratch which motivated me to join IGCAR. As I was very specific about food and even though I foresaw that there was going to be a difficulty, I prepared myself to venture into it. My family circle knew Department of Atomic Energy better than me and insisted that I move to Kota, Rajasthan. I would say that life at this Centre was professionally rewarding, as I saw FBTR taking its shape from day one of its inception and had the opportunity to participate in its design activities and be a part of the team in finding solution to problems whenever there was any operational difficulty. I was also associated with PFBR from day one, by writing the first document on what would be the pipe size of the reactor in the year 1975. I would like to share my memories of the green sheet on which I wrote the basics of pipe sizing. My other contributions to PFBR include preparation of large number of design documents and writing the entire portion of Heat Transport System for FBR-500. I can still write any portion for PFBR anytime on the areas in which I have worked without looking for any paper.

Shri S. C. Chetal is a Mechanical Engineer from Delhi College of Engineering and he joined IGCAR in 1971 after graduating from the 14th Batch of BARC Training School. Since, then, he has been engaged in the field of Fast Reactor Engineering and has made significant contributions towards design of FBTR sodium systems and components. He is the principal design engineer of PFBR and has made outstanding contributions towards the material selection, manufacturing technology, R&D design and construction of 500 MWe Prototype Fast Breeder Reactor. He is a member of many professional institutions and fellow of Indian National Academy of Engineering. He is a recipient of Indian Nuclear Society INS Award 2003 for contributions towards nuclear related high technology, National Design Award-2007 by Institution of Engineers, 2003 VASVIK Award, Agni Award for Excellence in self-reliance by DRDO for titanium sponge production, Certification of Appreciation by IAEA towards fast reactor technology and life time achievement award by System Society of India. His interests include pressure vessel and materials technology.

Though you are a mechanical engineer, in IGCAR people say you are well versed in Metallurgy than anybody else. How difficult was it to get familiarized in Metallurgy.

In 1975, a subcommittee was constituted for the material selection for the next reactor and I was the convenor of the four membered team. Though it was a tough job for me, I had a flair for materials and considered it an golden opportunity to explore into the new areas. I prepared myself for the new assignment by reading number of books available in the library on Metallurgy and Mechanical Metallurgy during that period. I can frankly tell that I read the book by "Dieter" on Mechanical Metallurgy twice and then started writing down the role of individual elements of austenitic stainless steel. I still remember the role of each element. In my second year of Engineering, one of my friend's father read my palm and told that I would be working on materials, at that time I asked him, I am pursuing mechanical engineering and how come I will work on Materials, his father replied that your palm shows strong association with materials. I always advise my colleagues on professional front to work on different areas given an opportunity. Finally I also admit that my interest is more oriented towards metallurgy than mechanical, if there are two papers before me one on metallurgy and the other on mechanical engineering, I would opt to first read metallurgy paper. I am also associated with materials selection for advanced ultra supercritical thermal plants. Apart from metallurgy I was associated with Civil Engineering jobs and served as member of Civil Engineering Safety Committee for PFBR. I sincerely advise all of you to accept assignments in different areas and exploit this opportunity for learning.

Materials are somehow related to Mechanical Engineering, but what was your experience in leading a Science Group

The myriad of training school is that we do not confine ourselves to a single discipline, I remember being taught chemistry and physics extensively in the Training School. I can sit with a physicist without any difficulty or hesitation and discuss on issues. Though scientist provide you with the numbers, the basics imparted by the Training School helped me in making the necessary perceptions. As an engineer I never found it difficult to lead a science group. The father of french fast reactor is a physicist. For contributing to a nuclear plant, I would say tagging to a single discipline is not required but desire to contribute, striving to learn and willingness to do much better are essential.

How was life back then at BARC training school?

The first five days of the week I would put in my best, preparing for the exams scheduled on Saturday, sixth day of the week. I will pour out my preparations on Saturday and seventh day of the week will be dedicated for playing cards. I was neither interested in sports nor cinema, but as a Punjabi, by nature, I have a desire for good food, I like white channa, black channa, rajmaa and chicken. We asked if he cooks food, he said absolutely no. We also asked him if he ever felt hectic or tired of writing exams and Shri Chetal told that he never felt hectic or tired of exams, as he always desired to perform well in the exams and be among the cream of toppers.

He recollected his college days and told that he along with Dr. R.B. Grover, Director, HBNI were few among the best seven students from his college who joined the Department. Since he was a day scholar he had to spend lot of time in travel and hardwork was never an issue for him. During interaction he went a step back to his school days and told that he would go out for a walk with his friends at around 10.30 P.M during which they had deep discussion on various disciplines of their academics such as trigonometry, chemistry etc.

Looking back at your life, what are the events you think has shaped your life?

Shri S. R. Paranjpe had enormous trust and confidence on me, much more than what I had on myself. He was a very tough person by nature, but very soft to me in whatever little I did. He involved me in finding solution to problems related to FBTR. The trust and confidence he had on me, made me realize my responsibilities and live up to his expectations. I would also say that self learning is far more beneficial than other modes of learning.

Sir, can you tell us about your command on codes

I learnt everything on my own. I realized the need to know codes for my profession in my early days. I took home and read one design code a day and everything would washout the next day. Then I decided to learn the codes through the back up documents and learnt the background for the codes. Even this afternoon you can see me in the library looking for codes which I haven't used in the past, I consider this as an opportunity to get to know these codes. I would read the codes in the following aspects, if there is a problem what code should

I see, how to handle any nonconformances in manufacturing and what are the latest codes. Reading codes are mostly boring to a large number of engineers, but I can read codes any time. Reading codes is merely not sufficient but applying them is all the more important. It is my experience that when we learn things on our own we would remember them forever, than learning from someone.

Sir, what are the areas you have worked for the PFBR

I have worked on portion of Heat Transport system, particularly Steam Generators, I was involved in material selection and the toughest job was getting the regulatory clearance for the PFBR. I had to work on all the disciplines and would go to the Safety Committee with a strong conviction of getting it cleared. At this point I would like to congratulate my colleagues, who put in their best efforts along with me in getting safety clearances for the PFBR. I feel that the training at the Training School and guidance of Shri S. R. Paranjpe in my early days of my career made me learn to solve any issue by dividing the whole problem into simpler modules, making approximation, work on minimizing approximations and then finding solutions.

What are the factors you consider important to motivate a team

The leader must

(i) be honest and frank with the team members

(ii) explain the team members clearly the role of the team in the Centre

(iii) be genuine to team members, To mention, I had some of my colleagues in my team who were ready to forgo their night sleep, in case I needed some information the next morning to take a decision.

(iv) resolve manufacturing issues the same day without postponing it

People often say that R&D organization, academic institution and manufacturing industry do have different views of same thing; however, they are never linked together? What is your view on this? What is the role of an organization like IGCAR in this context?

Academic institutions should impart concepts of fundamentals to the students. The engineer is expected to use the fundamentals in solving issues at the Industry. I would say that industry must not expect a fresh engineer to solve problem on technical issues on the very first day, but instead spend time on training them in their discipline as per the needs of the industry. Today the academic system, by and large is not as per the needs of the industry and to bridge this gap, academicians should spend some time in the industry and engineers with experience in industry must spend time at the academic institutes. This approach is needed, as engineers from industry will surely make students realize that life outside the four walls of the class room is entirely different. In order to bring a win-win situation, the large gap between industry and academic institute must be bridged and for this both academic institutes and industry must cross their boundaries. Our Centre has a good outlook on what an industry is, we are interacting with industry quite often for various components and can play a leading role by taking classes in the fourth year of graduate engineering degree or second year of post graduate engineering degree on how academic life will be useful for the industry, i,e. application of basics taught by academic institutes to an industry. For e.g. students must have studied about a crane theoretically, but they must be exposed to crane and its operation practically to know all the nuances. What is all the more important is the visit of students to the industry, where the industry gives them an outline of things and thereby inspires them to learn further.

Sir, you have been an engineer par excellence and an administrator, don't you think that two roles require entirely diverse set of skills and a person may not be able to do justice to both ?

Whether I am an engineer or administrator par excellence is left for others to comment. Both as an engineer and administrator, you need to have trust in your own people, be clear on what you are looking for and clearly and efficiently convey to them or give broad guidelines on what you are looking for. As an administrator you must not leave a decision for tomorrow. Personally speaking the discussion on a subject must be taken across the table, not through e-mail, I don't like the idea of exchanging e-mails within a group, as I feel solution to issues can be arrived at in lesser duration in discussion mode across the table. The most important aspect is senior and younger colleagues should work together like a family, because one fine day the younger colleague will occupy the chair of senior colleague. So we have the responsibility of training the youngsters for higher positions taking them into confidence on the larger perspective of an issue and asking them to work on small module of the issue.

He also advised us to be flexible in life and always presume that our colleagues may be more correct than us. When we go for a meeting we must get convinced with other's decision or be in a position to convince others with our decision on an issue. We should not postpone decision making or impose our decision on others but at the same time take decision.

Today many enthusiastic youngsters join new projects, but when the project doesn't progress as per the schedules or when they get stuck up somewhere in middle due to lack of proper guidance, the youngsters get demotivated. What would be your advice for such youngsters.

First of all I would like to tell that life is full of challenges and there may be times when you are not in a position to find a solution for an issue, but you must have a strong desire, put in your best efforts and work harder to solve the issue, instead of getting demotivated. For example, Shri S. R. Paranjpe asked me to design the safety device for the FBTR, the rupture disk for the steam generator that was very expensive and had to be imported from U.S.A, and added that as an Mechanical Engineer you must be able to find a solution. I had no idea of the imported item. I tried very hard but did not succeed and give up, tried again and again, learnt the fundamentals of metal forming, got some rough idea, practiced the idea and was finally successful. When the time came for import, I told Shri S. R. Paranjpe, 50% could be Indian and the rest 50% we could import. Shri S. R. Paranjpe, replied that " I have trust in what you have done" and it will be 100% Indian. I would like to pass on to the youngsters that first you must have a confidence that one day you will find a solution to the issue and second I must confess that you should have seniors who do not get upset on you for not finding a solution. Youngsters please do not get demotivated, instead keep thinking about the issue all the time and definitely some ideas will crop up in your mind for solving the issue. As I told in the beginning, life is full of challenges and we must face the challenges.

What are the difficulties you faced while working for the PFBR?

I absolutely did not face any difficulty while working for the PFBR. The toughest thing we were facing was the safety regulatory system. Since most of the colleagues were having experience on thermal reactors, they would view PFBR as a thermal reactor from safety point of view on a number of safety aspects. It took a good amount of time for us to converge. My message or advice to you is in areas where the decision of safety committee is not coming in line with your ideas, accept because they are also experts in their own way. When you feel that the decision is deviating too much from a good solution, you can still discuss with them but in a rather polite way. During the technical discussions, there could be harsh comments and observations. I would say that in your professional career never be harsh to your peers or juniors. You must give a feel to your juniors that you are always available to them and spend time with them. I did teach my juniors, who would like to learn things on a fast track mode instead of self learning mode, on a few Saturdays. You must be a senior friend to the juniors and lead them to right track. Without the hard work of your colleagues and effort of the juniors you cannot accomplish a task.

Your view on the synergy between various energy sectors like nuclear industry, thermal power sector and solar power sector...

In India 1/3rd of the population is starving without energy, then from where does the question of competition arise. A large part of Indians cannot afford expensive power. The government may give subsidy for renewable energy initially but it would be difficult for the government to continue the subsidy on a long term basis. We must make best use of natural resources, in fact our Centre along with BHEL and NTPC is working on the effective utilization of coal through advanced ultra supercritical technology. Our country needs more power for basic needs as well as industrialization and hence there is ample scope for all the energy resources.

I would like to insist that we must have sympathy for less privileged and see what we can do for them.

As an aftermath of the Fukushima Disaster were any last minute design changes done for PFBR.

No, Unfortunately there was a severe Tsunami of 4.7 metres, on December 26, 2004. The disaster damaged the civil raft structure and we raised the elevation level further. The design basis for Tsunami was subsequently arrived as 7.3 metres with the help of an IIT professor. PFBR, as built, has an elevation, safe for 9.3 metres, against the natural disaster like Tsunami/cyclone. Also, we can handle indefinite station black out as the decay heat removal system of PFBR is based on natural convection.

Do you feel that bias and phobia of people is a challenge to the growth of nuclear energy sector in India? What role we must play here?

I would say the protest is a political wind to score against each other. Frankly speaking nothing is 100% safe. For example accidents may occur while children cross the road. To avoid this we neither stop laying roads or prevent students from going to school. In the same manner nuclear reactors are built with high level of safety, but it so happens that vigor of the natural calamity is sometimes higher than that seen in the past or expected. Hence, what is essential for us is to strike a balance between safety and cost.

Looking back, Sir do you have any professional regrets or anything that you feel could have been done better?

By God's grace, I don't have any such regrets in my career as not a situation has arose where I would have felt that the other decision would have been far better. I believe that, before deciding on an issue, we must listen to all those who are involved in that issue irrespective of whether they are juniors or seniors and also must learn not to make any adverse remark on any of them.

Innovations are important in an organization like ours, In the last four decades that you have been involved with the fast breeder reactor technology can you list down the top three innovations you came across ?

I feel the word innovation is a very strong word and would say that we have taken a number of challenges. Most of the reactor components, first of a kind, had been challenging for the Indian industries. The challenges have been met but it took longer time to accomplish the task. Having the experience of building a 40 MWe reactor, we decided to construct a 500 MWe Prototype Fast Breeder Reactor and not a 100 MWe reactor. Looking at the design and construction of PFBR, which is in the final stages, I personally feel that we have made the right decisions and this experience would definitely help us in the construction of next reactors, in a relatively short period.

What has been the role of your family in your life? In case of a conflict between your professional and personal life what would you have done?

I need to mention that my wife was extremly supportive. I spent most of the time at office and she took the responsibility of taking care of the family. On the home front I did only one activity; I taught my two children. Another important thing is my wife was never worried about my too much attachment with office. At times she used to gather some information on certain issues from the neighbour and ask me, I neither said yes nor no. One advice I would like to give you all is to delink official and personal life.

What word of advice would you like to give the young engineers/scientists joining IGCAR/DAE?

Please put your heart and soul and work on your assignments. Don't go by others perception. Never switch your interest, just because you are assigned a difficult job. In case you have interest in some other area, complete your assignment and then ask for a change. I also shifted from development to design, because I was much interested in design, but I asked for a change after successfully completing my assignments in development. The Centre will put forth enough opportunities to do new things, you must have a desire and will to contribute effectively to the Centre. Wish you all the best. I am sure you will all rise and the Centre will also rise to greater heights.

This new feature of interviewing eminent persons by young officers has commenced from this issue. A team of young officers comprising of Ms. Vinita Daiya, Ms. Sumitra Santra, Ms. Diptimayee Samantray, Shri Anindya Bhattacharyya, Shri Ashish Shukla, Shri Avik Kumar Saha and Ms. K. Saipriya has been identified to conduct these interviews periodically.

Experimental Determination of the Solidus Temperature of Mixed Carbide Fuel (Mark I) of FBTR

Pure metals and crystalline substances possess a sharp melting point while many alloys could melt over a range of temperatures progressively. The temperature at which the melting sets-in in a multiphasic alloy is called as its "solidus" temperature while the temperature at which the entire alloy turns into a liquid corresponds to its "liquidus" temperature. Among the physicochemical properties of multicomponent multiphase alloys of relevance to nuclear fuels, their "melting point" is an important fundamental property. Since these are multiphasic materials the term "melting point" is rather inappropriate. The lowest temperature at which liquid appears first when the fuel is heated, is more relevant. This could be the solidus temperature or the temperature pertaining to a phase equilibria in which liquid is formed. A reasonably accurate knowledge of this temperature is necessary in order to estimate the linear heat of the fuel.

The onset of melting in a substance could be determined by a variety of techniques. These techniques use the change in a physical property which accompanies melting. The physical property in question could include but not limited to the variation in the following; specimen temperature, its resistivity, reflectivity, emmisivity, thermomechanical property (volume or linear expansion), thermophysical property viz., enthalpy, vapour pressure, chemical potential etc. The most popular technique among these is the differential thermal analysis (DTA) in which the relative change in the specimen temperature is monitored with respect to an inert reference. Commercial equipments are available which could accurately determine the melting transitions up to at least 2273 K. However, difficulties are often encountered in using these equipments in the determination of melting points of radioactive and chemically reactive alloys. These are mainly caused by the reactivity of the molten alloy with the container and in the customization of these equipments to suit measurements in a controlled ambience, like in a dry box, the latter is necessary for handling radioactive substances. In order to circumvent these experimental difficulties a new experimental facility (Figure 1) was established in our Centre for the determination of melting point of fuel materials. This set-up is based on the "spot" technique, a thermo-optometric technique developed at the Argonne National Laboratory, USA. Many investigations have been carried out by S. P. Garg's group at BARC, Mumbai, earlier on refractory metal-uranium systems in the past. In this technique the change in sample reflectivity is monitored during melting. From the image formed by the molten liquid the temperature at which melting sets-in is recognized. This technique is amenable for remotization, simple

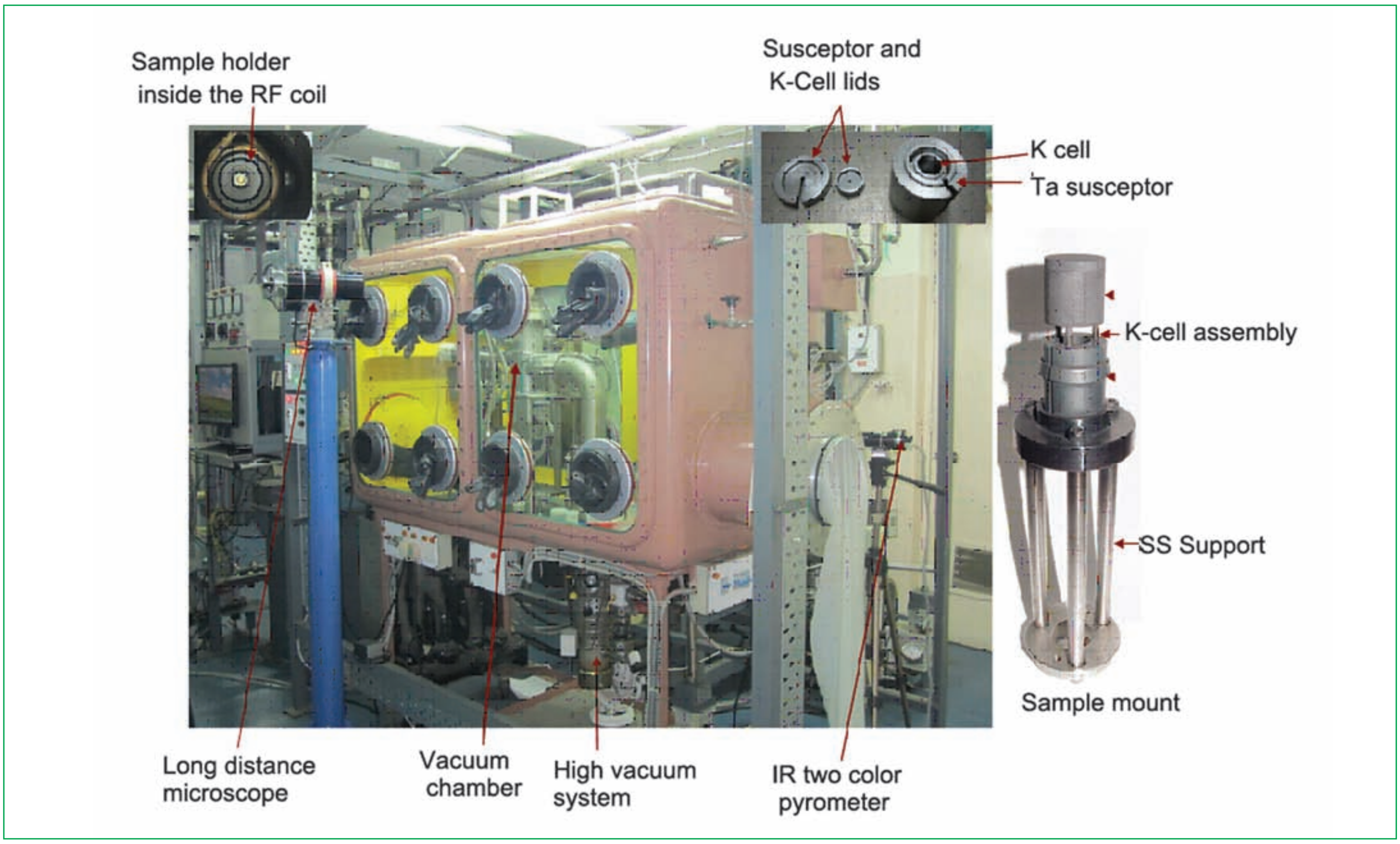

Figure 1: Photograph showing the experimental set-up used for measuring the solidus temperature of mixed carbide fuel (Mark I) of FBTR

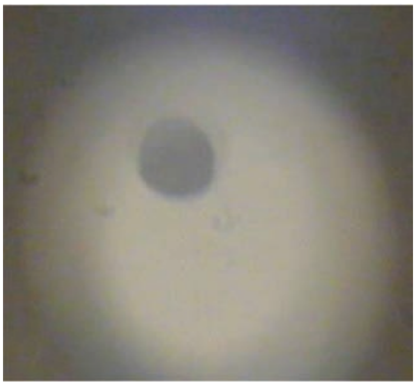

Figure 2: Full spot at the melting temperature of zirconium

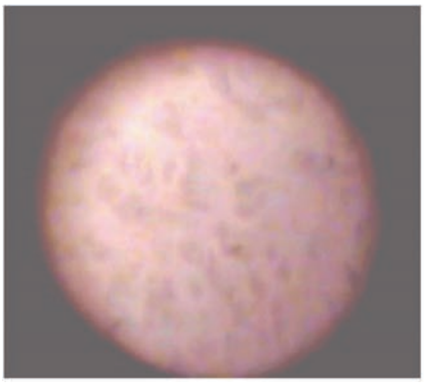

Figure 3: Broken spots at the solidus temperature of mixed carbide fuel (Mark I) of FBTR

Table 1: Measured values of solidus temperatures of Mark I and Mark II fuel of FBTR

FBTR Fuel	Solidus temperature (K)	Technique used
Mark - 1	2161 ± 5	Present study, Spot-technique
Mark - 1	2148 ± 25	Incipient melting *Sengupta et al. BARC*
Mark - 2	2193	Dilatometry *Majumdar et al. BARC*

and quick. In a typical measurement the sample held in a container with lid having a small orifice (a Knudsen Cell) typically about 0.5 mm diameter is heated under vacuum (~ 10^{-6} mbar) remotely with the help of electromagnetic induction (radiofrequency). The orifice of the cup is viewed remotely with the help of a magnifying device. Upon melting the image of the orifice appears on the molten surface as a black spot (Figure 2). If the melting is partial (like in the case of a solidus temperature) then many tiny black spots appear (Figure 3) which coalesce to form a single large spot at the liquidus temperature. Many experimental improvisations were made to the experimental set-up used by the inventors of this technique. With the help of these refinements, (i.e. by replacing the low magnification pyrometer telescope with a long distance microscope fitted with a video camera) the melting could be videographed and a high temperature remote low magnification microscopy of the sample could be carried out. Further the investigations carried out at our Centre also resulted in devising a new technique called as the illuminated spot technique with the help of which the temperature limits of utility of this technique could be extended to temperatures far below incandescence (i.e. below 1173 K).

The accuracy of this experimental technique was established to be ± 2 K with the help of measuring the melting points of pure metals as well as by investigating the solidus and liquidus temperatures in well known binary alloy systems.

With this experimental system, the solidus temperature of Mark-1 FBTR fuel (a biphasic mixture of the mono and sesqui carbides of U and Pu with Pu / (U+Pu) = 0.7) was measured. About 700 mg of the pellet was taken in a “carburized tantalum” cup that was held in a molybdenum Knudsen cell. This assembly was heated under vacuum at a heating rate of 1 K/min above 2130 K and at 20 K/min below 2130 K. At 2161 K, a few “broken spots” were formed that corresponded to the solidus temperature of the Mark I FBTR fuel. This is the first direct measurement of the solidus temperature of Mark I fuel of FBTR. Earlier measurements employed rather an indirect technique, viz., incipient melting (Table 1). Our data is within the error limits of the earlier measurements and is more accurate than the previous measurements.

After the experiments, the melting of the fuel was confirmed by removing the sample and photographing the frozen alloy (Figure 4) which evidenced slumping. Further efforts are underway in order to measure the solidus temperature of Mark II fuel as well as U-Pu-Zr alloy fuel.

Figure 4: Mark I Mixed carbide fuel pellet of FBTR after melting and solification

Reported by K. Ananthasivan and colleagues
Fuel Chemistry Division, Chemistry Group

Application of Ion Accelerators for Studies on Defects and Diffusion in Structural Materials

The ever increasing energy demand has led to the introduction of nuclear energy option alongside other sources of energy. The water reactors and fast breeder reactors with closed fuel cycle are proving to be inevitable technology options for providing sustainable energy security. Growing concomitantly with the fast breeder reactor technology is a host of materials development issues. While placing emphasis on increasing burn-up of fuels and increasing breeding, one reaches the limits of material's performance. Therefore material science and engineering has exerted considerable influence on the advancement of fast reactor technology.

Among various criteria viz., corrosion resistance, high temperature strength to be considered for choosing materials for application in fast reactor, irradiation induced dimensional changes which are brought about by void swelling phenomenon to core structural materials like fuel clad and wrapper is important. Irradiation in a material produces point defects (vacancies and interstitials) in equal numbers; the majority of which annihilate and a small remnant fraction cluster to form stable irradiation induced defects. Voids are such agglomerates of vacancies and are nucleated in a material when there is a super-saturation of vacancies as compared to the vacancy concentration at thermal equilibrium. Voids are neutral sinks in the sense that they attract both vacancies and interstitials alike. In order that the void may grow, the net flux of point defects flowing to the nucleated voids should be vacancy dominated. This is achieved by the presence of sinks like dislocations in the material, which have a bias for attracting interstitials in comparison to vacancies, thus increasing the current of vacancies flowing to the voids. The presence of voids causes volumetric swelling of the material and the related undesirable dimensional changes in structural materials. Therefore, resistance to void swelling and creep are major considerations while exercising choice of materials for the core components.

Directives to design materials which are resistant to void swelling have a common bearing (depending on the temperature regime) in order to limit vacancy clustering: enhancing the mutual recombination of point defects and increasing the vacancy mobility so as to reduce the local vacancy super-saturation. Additionally, introduction of dense nano-sized precipitates, which provide large precipitate matrix interfaces where point defects can annihilate and also can disperse transmutation gases to fine sizes in order to limit void nuclei below sizes critical for their growth, has been resorted to. Addition of minor elements viz., Ti, P, Si and C to austenitic steels have shown to exert a profound influence on reduction of void swelling, by binding with point defects and formation of precipitates with high number densities. Thus, practical applications have necessitated a full understanding of the underlying physical processes involving solutes viz., the phase formation, diffusion, their interaction with defects, dislocations and other second phase particles during irradiation.

Focus of the present article is two fold (a) to address diffusion behavior of silicon in D9 steels and the role of dislocation microstructure in influencing its diffusion behavior and (b) to study interaction of implanted nitrogen with irradiation induced defects in D9 steels.

Silicon is a fast diffusing element in D9 steels, which increases the effective vacancy diffusion coefficient, consequently leading to the reduction in void nucleation rates. In order to model such complex influence of solutes on irradiation induced defects, knowledge of their diffusion behavior is essential due to their considerable redistribution during irradiation; and this therefore is the motivation to study silicon diffusion behavior in D9 steels. The diffusion behavior here is observed experimentally by implanting an isotope of silicon in D9 steel and following the diffusional broadening of the implanted profile at various temperatures. The determination of profile broadening is obtained using resonance nuclear reaction analysis.

As regards to nitrogen, it is incorporated in D9 steels during processing and is smaller sized than carbon, which in solution is known to have a propensity to bind with vacancies, thus playing a vital role in affecting swelling. Hence it is of interest to study the interaction of nitrogen with irradiation induced defects. D9 steel has been subjected to nitrogen implantation and the distribution of nitrogen atoms between the regions of implanted and peak damage depths are obtained using resonance nuclear reaction analysis. A considerable deviation of the experimental depth profile of nitrogen from the theoretical implantation profile obtained using Monte-Carlo codes is observed. This issue is addressed through studies of vacancy defects by employing depth resolved positron annihilation spectroscopy along side resonance nuclear reaction analysis.

Ion beam analysis is a diverse group of characterization techniques which has been applied to every class of material in discrete applications, where the interest is in obtaining quantitative elemental depth profiles in the surface or near-surface regions extending up to a fraction of an mm. Depending on the various modes of ion beam interactions with atoms and nuclei, a host of techniques have evolved each having its own characteristic with respect to detected atoms, depth resolution and sensitivity.

Among the ion beam analysis techniques, nuclear reaction analysis (NRA) pertains to detection of reaction products (usually the lighter particle b) which emanate from a nuclear reaction $a + A \rightarrow b + B + Q$ (typical representation), in order to obtain quantitative depth profiles of A. Reactions with high Q are usually resorted to, in order that the lighter particle might emanate with higher energies; hence facilitating detection of nucleus A located at greater depth in the sample. In special cases where nucleus B is in the excited state the γ-rays emitted during the de-excitation can also be utilized for depth profiling. The power of nuclear reaction analysis vests on its radical isotope selectivity, making it a powerful tool for studies on self diffusion. The resonance nuclear reaction analysis is a subtle variant of the nuclear reaction analysis, where the energy of the incident particle is tuned to energies where enhancement in reaction cross-section is observed, thus increasing detection sensitivity. Superior depth resolution and increased sensitivities are distinct characteristics of resonance nuclear reaction analysis.

Depth resolved positron annihilation spectroscopy studies are carried out by a magnetically guided variable energy positron beam system. The mono-energetic positrons obtained from such a system are thermalised at a mean implantation depths determined by their energy and density of the material. There is a high probability of capture and annihilation of thermalised positrons at open volume defects. Information pertaining to vacancy-defects can be obtained by measuring the annihilation characteristics of the 511 keV γ-rays. A defect sensitive line shape S-parameter, defined as the ratio of the counts in the central region (511±1 keV) to the total photo peak region (511±10 keV), is deduced from these measurements. The presence of the vacancy-defects leads to narrowing of Doppler broadening curve, hence resulting in an increase in S-parameter.

Studies on silicon diffusion in D9 steel

Solution annealed and cold worked D9 samples are implanted with 200 keV ^{30}Si ions to a fluence of 3×10^{16} atoms cm^{-2}. The depth profiling of silicon in ^{30}Si implanted D9 samples was carried out using the 620 keV resonance ($\Gamma\sim$ 68eV) of the $^{30}Si(p,\gamma)^{31}P$ nuclear reaction. The profiling experiments involve increasing incident proton energies beyond 620 keV in steps of 1 keV and collecting the gamma rays emitted in the energy window 6.8 – 9 MeV. The gamma ray yield in this energy interval served as the signal and is proportional to the concentration of the ^{30}Si at depths described by the incident energy. The relationship between the incident energy and the depth at which the reaction is taking place can be established by taking into account the energy loss of protons in the alloy.

The experimentally obtained depth distribution of the implanted silicon as illustrated in (Figure 1a) is a Gaussian profile with centre and full width at half-maximum (FWHM) as 120 and 95 nm respectively. This implanted silicon distribution serves as the marker layer and its broadening is used for following the diffusion behavior of silicon in D9 steel samples. The silicon implanted sample was annealed in steps of 50 K in vacuum for a duration of 30 minutes at each step, followed by resonance nuclear reaction analysis experiments after each annealing. It is found that there is no significant change in the width of the implanted profile in the sample up to 873 K with the annealing time of half an hour. After prolonged annealing at 873 K at different increments of time it was found that, the implantation profile revealed a discernible change after eleven hours (Figure 1a). Further, four numbers of Si implanted D9 samples were annealed independently at different temperatures from 923 to 1073 K in steps of 50 K for different time duration. Figures 1a and 1b illustrate the diffusion profile of silicon in the

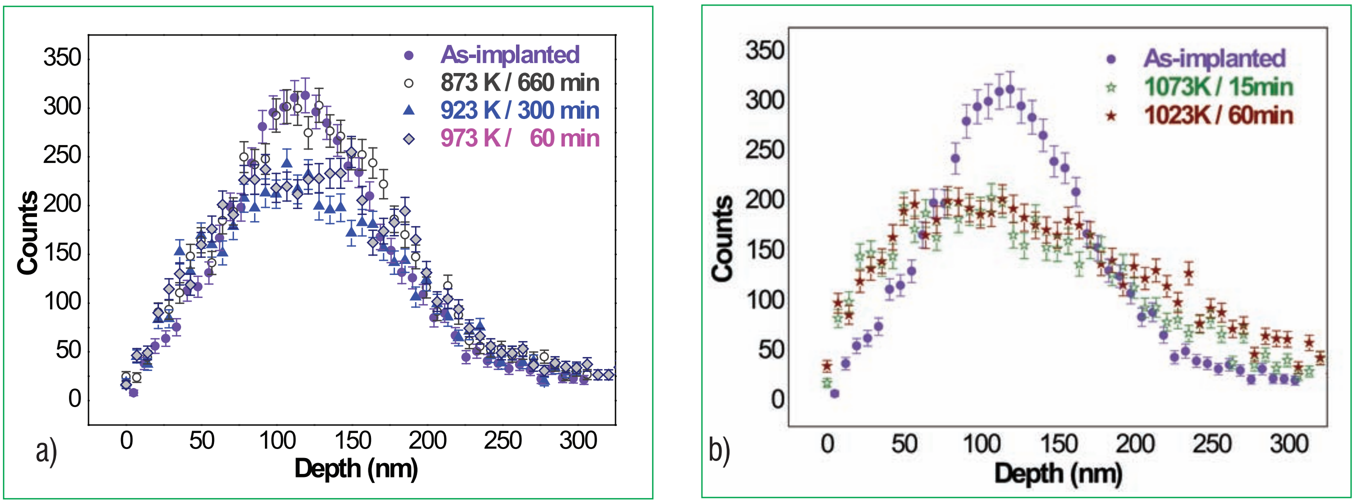

Figure 1: Broadening of the depth profiles of implanted ^{30}Si as determined by resonance nuclear reaction analysis measurements at different annealing temperatures. Different time duration of annealing as indicated in figure was followed in order to obtain measurable broadening

temperature interval of 873 to 1073 K for different time durations. A model of an infinitely thin source diffusing into a semi-infinite system is considered and the profile broadening for each of the annealing temperatures T is used to deduce the diffusion co-efficient D(T). The Arrhenius plot is shown in Figure 2 and activation energy of 2.23 eV is obtained for the silicon diffusion in solution annealed D9 steel. The activation energy deduced here for silicon diffusion is much greater than the experimentally determined effective vacancy migration energy (1.13 eV) in solution-annealed D9 steel. Hence, silicon diffusion in the solution annealed D9 steel is regarded as vacancy-assisted. The present value of activation energy for silicon diffusion is lower than a previously reported value of 2.43 eV for silicon diffusion in fcc Fe. Addition of fast diffusing solutes can increase the vacancy migration and in turn the diffusion of solvent atoms. Apart from silicon it should be noted that another fast diffusing species viz., titanium is present in D9 steel. Titanium being an oversized element in the D9 alloy would diffuse via vacancy mechanism. Hence, the relatively lower activation energy obtained here for silicon diffusion in solution annealed D9 steel is ascribed to the increased vacancy migration due to the presence of both silicon and titanium in D9 steels. Therefore, the present observation strongly suggests that the synergistic effects due to the presence of various fast diffusing solutes contribute to enhanced vacancy mobility and the consequent void swelling suppression. Similar experiments in cold worked D9 steels have shown a decrease in the activation energy for silicon diffusion to about half of its solution annealed counterpart (Figure 2). While discussing the importance of cold working in obtaining decreased swelling compared to its solution annealed counterpart one resorts only to comparison of the formation of dislocation controlled metal carbide precipitates. This study has shown that the enhancement in the diffusion of the fast diffusion solute (which is added for decreased void nucleation at high temperature) due to cold work is also to be reckoned as a factor causing considerable influence on swelling.

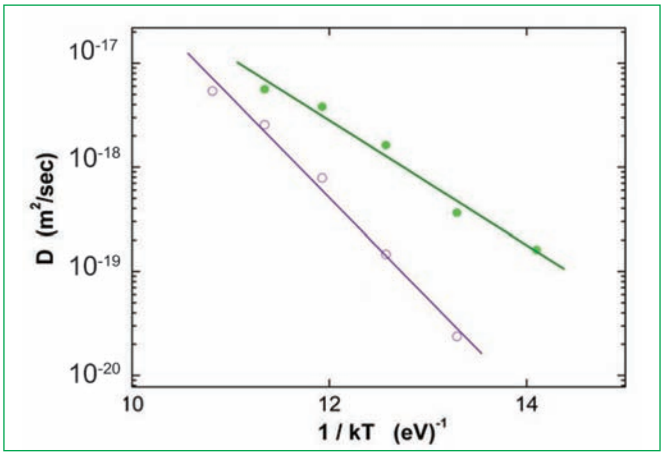

Figure 2: A comparison of activation energy for silicon diffusion in cold-worked D9 samples (● E_a = 1.38 ± 0.12 eV) and solution-annealed samples (○E_a=2.23 ± 0.13 eV)

Studies of redistribution of nitrogen in D9 steels

Solution annealed D9 samples are implanted with 30 keV ^{15}N ions to a fluence of 1×10^{15} and 5×10^{15} atoms cm^{-2}, designated as low and high fluence samples respectively. Depth profiling of ^{15}N has been carried out using the 429 keV resonance of the $^{15}N(p,\alpha\gamma)^{12}C$ reaction. This reaction is ideally suited for obtaining quantitative depth profiles of nitrogen with superior depth resolution (~3 nm at the surface) and high sensitivity (~0.01 at%). The γ ray counts in the energy window of 3.2 to 4.7 MeV are integrated to serve as signal for depth profiling of nitrogen and is proportional to the concentration of nitrogen. The experimental depth profiles of ^{15}N in low fluence and high fluence samples are shown in Figures 3a and 3b respectively. The depth profiles in both samples exhibit an asymmetric Gaussian profile near the surface. The experimental data has been fitted into two Gaussians with a variance of 0.95. The simulation of the implantation profile and the corresponding defect distribution produced (Figure 3c) is obtained using a Monte-Carlo program - SRIM. The peak positions of the fitted Gaussians of the experimental profile coincide with the peak

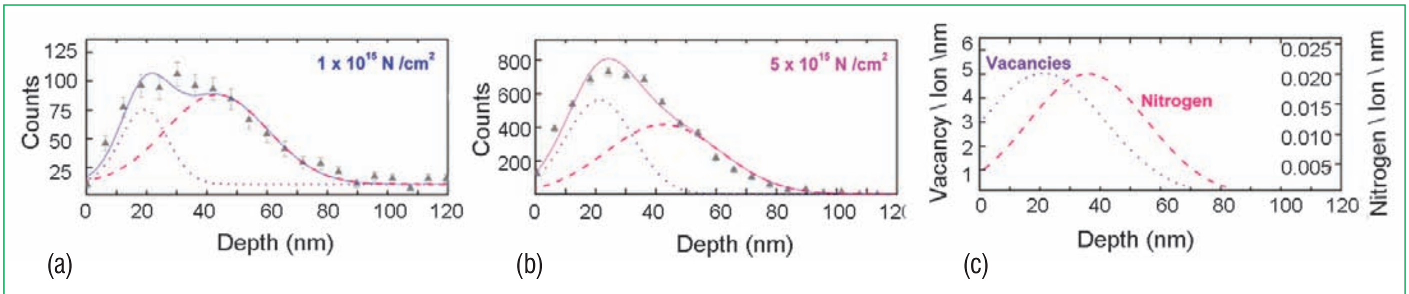

Figure 3: Experimental depth profile of ^{15}N implanted in steel to a fluence of (a) 1x10^{15} N/cm^2 and (b) 5x10^{15} N/cm^2 obtained using resonance nuclear reaction analysis and (c) SRIM simulation of 30 keV nitrogen in steel depicting the implantation and vacancy profiles. The experimental data points (closed triangle) are fitted into two Gaussians whose peaks are centered at ~ 20 nm (dotted line) and 42 nm (dashed line)

damage region and the projected range of implantation, defined by the SRIM simulation. It is observed that a part of implanted nitrogen atoms is located around the peak damage region in addition to being present at the predicted range of implantation. A comparison of the relative intensities of nitrogen residing in the peak damage region and implanted regions of the samples show that in the higher nitrogen fluence implanted case, a greater fraction of nitrogen resides in the peak damage region as compared to its lower fluence implantation counterpart.

In order to explore the possibility of nitrogen decorating the vacancies around the peak damage region, the depth profile of vacancy defects is probed using positron annihilation spectroscopy. Figure 4 shows the variation of normalized S-parameter as a function of positron energy for un-implanted, low and high fluence samples. The top axis shows the mean implantation depth of positrons in steel. For the un-implanted sample, the S-parameter near the surface is high (due the surface defect states), which gradually decreases and saturates towards the bulk value (beyond 16 keV). For the sample implanted with low fluence nitrogen, the entire curve lies much above that of the un-implanted sample which indicates the presence of implantation induced vacancy-defects and in addition, the S-parameter has higher value at the depth closer to the surface region. The high fluence sample displays a similar behavior as that of low fluence sample excepting at low positron energies. There is an unusual decrease in S-parameter (even lower than that of low fluence sample) for positron energies less than 5 keV. This is unexpected as larger fluences usually result in more damage, giving rise to production of a greater concentration of vacancy defects. The decrease in S-parameter occurs in a region corresponding to the peak damage as predicted by SRIM. The decrease in S-parameter can be brought about by a decrease in vacancy defect density or due to the increase in core electron contribution. In the case of the high fluence implantation, a decrease in vacancy defects can be brought about by overlap of collision cascades due to the higher fluence. But this should result in decrease in vacancy defects throughout the damage region. As evident from the Figure 4, for the higher fluence implantation, a region with low S parameter occurs only for a depth of ~ 30 nm from the surface. Hence the occurrence of a region with lower S parameter can be construed as due to an increase in core electron contribution. Decoration of vacancies with nitrogen atoms to form vacancy-nitrogen (V-N) and related complexes could have resulted in increase in core electron contribution. Even though defects as seen by positrons extend till ~90 nm for both low and high fluence samples, only sub-surface defects (~30 nm) forms complex with nitrogen, due to the excess vacancy concentration in the region. Reports on the interaction of nitrogen with vacancies in α-iron have shown that nitrogen atoms in ferrite form complexes with mono vacancies.

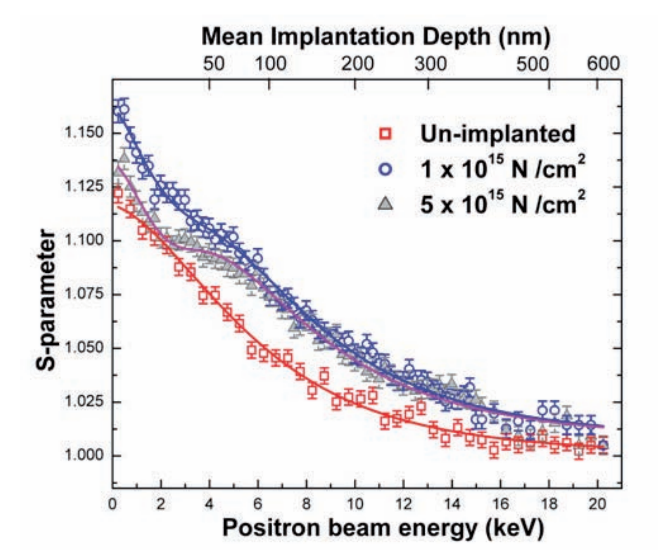

Figure 4: Variation of normalized S-parameter as a function of positron beam energy for un-implanted (open square) and low fluence (open circle) and high fluence (closed triangle) samples. The solid line through the data points is a result of VEPFIT analysis

Though the binding energy is expected to be smaller, vacancy nitrogen binding is known to occur in the austenite phase. As regards to the driving force behind such redistribution: irradiation leads to build up of stress at range of implantation and the system attempts to lower its energy by the movement of nitrogen from range of implantation to peak damage region. Thus, the total energy of the system is lowered by an amount equal to the binding energy of the V-N and its complexes.

Through the annals of literature related to nitriding studies which involve ion implantation, deviation from predicted Gaussian profiles in the form of movement of the profiles towards the surface has been clearly observed. Though a majority did not provide any discussion on this aspect, a few have invoked computer codes to account for sputtering and have obtained good fit to the experimental depth profiles. But in the present case, owing to low fluence implantation, the role of sputtering (sputtering yield $\approx$1.3 atom/ion) in causing a deviation to the nitrogen profile should be ignored. One particular report that discusses such redistribution contemplates trapping of nitrogen in high concentration of vacancy clusters near the surface of the sample but does not provide any experimental validation. Thus through combinatorial experiments, the possibility of role of V-N complexes in redistributing nitrogen from the implanted region to the vacancy excess is here proposed.

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Young Officer's FORUM

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Instrumentation and Control System for Sodium Testing of Fuel Handling Machines

In Prototype Fast Breeder Reactor, there are two fuel handling machines to handle fuel, absorber and blanket sub-assemblies within the core and to transfer the sub-assemblies out of the core. They are inclined fuel transfer machine (Figure 1) and transfer arm (Figure 2). Transfer arm is an offset type fuel-handling machine used for handling fuel, blanket and absorber sub-assemblies with its outer sheaths. Its functions include loading and unloading in the core, storage locations and in in-vessel transfer port (IVTP). Inclined fuel transfer machine is used to transfer the spent sub-assemblies from in-vessel transfer port in reactor containment building to ex-vessel transfer port in fuel building and also to transfer the fresh sub-assemblies from ex-vessel transfer port to in-vessel transfer port. In PFBR, these fuel handling machines are operated remotely from the handling control room console or panel. During maintenance/ commissioning, they are operated remotely from reactor containment building–local control centre. These machines are manufactured by different manufacturers. The operations of these machines will be tested in sodium before they are deployed in the reactor. A test set-up has been made in large component test rig at Fast Reactor Technology Group for this. The machines are planned to be tested in actual reactor conditions for 10% (approximately) of total cycles envisaged in the reactor which comes out to be 600 cycles.

Instrumentation and control system used for this test set-up is similar to the one used in reactor. Design of test set-up, procurement of instruments, installation and commissioning of all the field instruments, variable speed drive (VSD) panel, linear actuator control panel, preparation of control logics were done by Reactor Design Group. A VME based control panel similar to the one used in reactor, developed by Electronics Instrumentation and Radiological Safety Group is used in this test set-up.

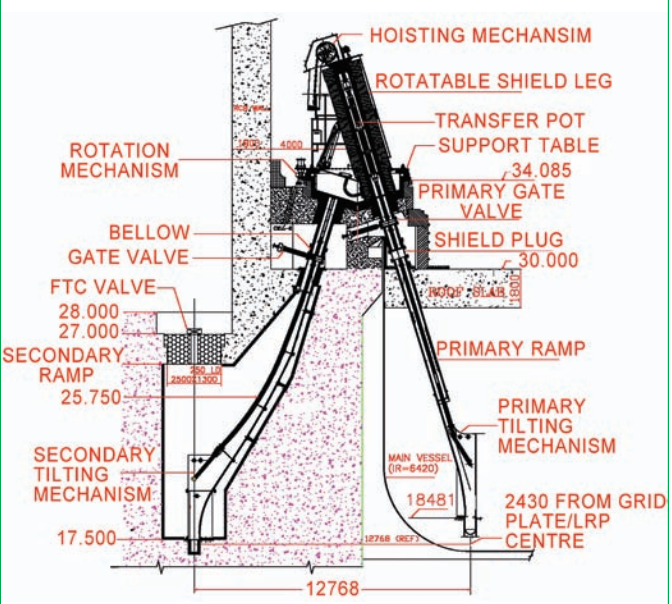

Figure 1: Inclined fuel transfer machine

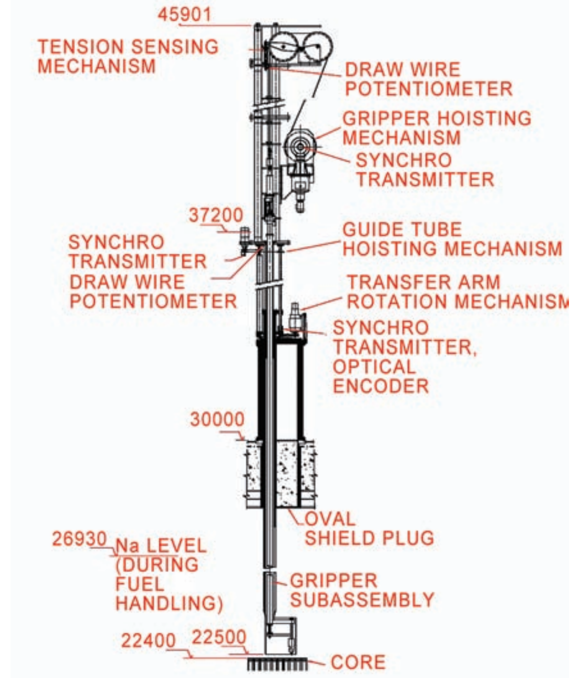

Figure 2: Location of field sensors in transfer arm

Instrumentation

Fuel handling machines are provided with diverse continuous position-monitoring to overcome the single failure criterion and common mode failure for monitoring the positions. Typically for transfer arm, synchro and draw wire potentiometer are used for guide tube and gripper hoist mechanisms. Synchro and optical encoder is used for top structure rotation mechanism. Discrete positions of the gripper hoist, guide tube, top structure, gripper hoist lock and gripper finger are sensed using redundant limit switches. Linear variable differential transformer is used for monitoring the gripper finger movement continuously. Load on the gripper hoist is measured using load cell which indicates about the "Exertion force" or "Insertion force" that is being applied while removing or inserting a sub-assembly. Figure 3 depicts the interfaces between transfer arm/inclined fuel transfer machine with the Instrumentation and control system.

Control Panel

Fault tolerant VME based dual redundant real time computers (RTC) with switch over logic circuit, is provided in PFBR to control the fuel handling machines. In case of failure of online real time computer, the switch over logic circuit switches the control to the other real time computer which becomes online. Similar system is used for testing the machines in large component test rig. Signal from all sensors are wired to the both real time computers. Switch over logic circuit always ensures through the ORing logic circuit that only the online real time computer drive the final control elements. Interface is provided for the real time computers to transmit all the transfer arm signals via ethernet output to the display station for GUI. All the analog signals from the field are connected to the signal conditioning modules and the output of signal conditioning modules are connected to both the real time computers. All the digital inputs are multiplied by using relays and connected to both the real time computers.

Operator Station

Transfer arm/inclined fuel transfer machine are required to be operated remotely from control room in PFBR. Similar panel with controls and indications exactly matching the handling control room panel in PFBR is used for the operator to remotely operate the machine during testing. All the information viz. discrete positions, continuous positions, drive selections, sequence selections, error or alarm messages related to the machine are displayed by means of GUI in the display station and also by means of hardwired lamp indications in the operator panel provided for testing. Three dimensional graphics of the operation of machine and fuel movement is provided in the display station. All the data / messages / alarms that correspond to actuation of limit switches, continuous positions and completion of various

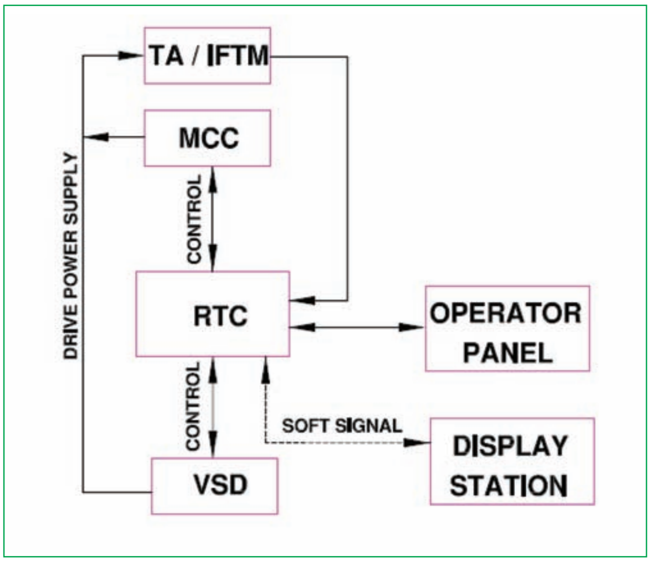

Figure 3: Interfaces of transfer arm/inclined fuel transfer machine machine with the I&C system.

operations are logged in the hard disk of the display station for verification.

Variable Speed Drive and Motor Control Centre (MCC)

Transfer pot drive of inclined fuel transfer machine and guide tube, gripper hoist and top structure drives of transfer arm are controlled by variable speed drive to achieve the positioning requirements and to reduce the fuel handling time.

The transfer pot hoist of inclined fuel transfer machine is normally operated at 67 mm/s corresponding to 100% of full load speed of the motor. The speed of transfer pot is reduced to 9 mm/s corresponding to 15% of full load speed of the motor during the bottom most travel in the tilting mechanism, gate valve and shield plug discontinuity and also during the top most 500 mm travel.

The guide tube of transfer arm is normally operated at 0.66 mm/s corresponding to 20% of full load speed of the motor.

The gripper hoist of transfer arm is normally operated at high speed (35 mm/s corresponding to full load speed of the motor). The bottom and top most travel of 500 mm each, are performed at low speed (7 mm/s corresponding to 20% of full load speed of the motor).

Top structure rotation mechanism of transfer arm is rotated in two different speeds namely 151 arc minutes/s (corresponding to full load speed of the motor) and 20 arc minutes/s (corresponding to 13% of full load speed of the motor) to achieve the desired positioning accuracy. If the distance between current position and target position is above 5^{o}, then the top structure is driven at 151 arc minutes/s. As soon as the current position of the top structure drive approaches a distance of 5^{o} from the target

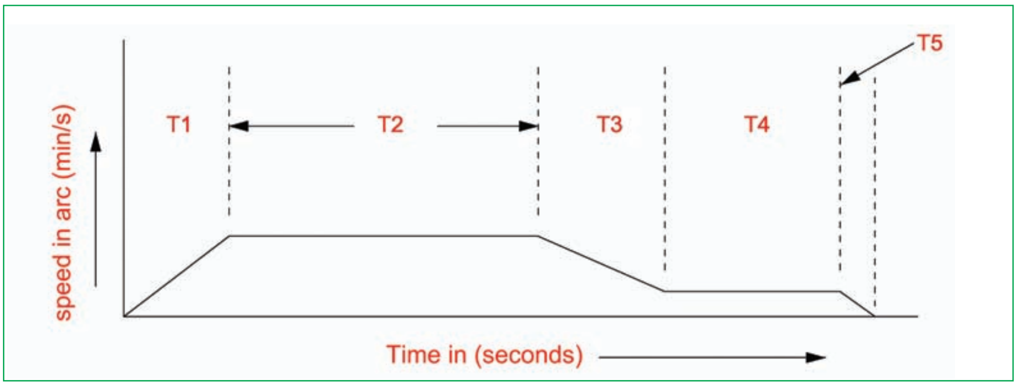

Figure 4: Speed profile of variable speed drive T1: Motor starting time to reach speed of 151 arc minutes/s. T2: Period during which the drive is driven at 151 arc minutes/s. T3: Coasting down period from a speed of 151 arc minutes/s to 20 arc minutes/s. T4: Period during which the drive is driven at 20 arc minutes/s. T5: Coasting down period from a speed of 20 arc minutes/s to halt

position, the drive is allowed to decelerate to a speed of 20 arc minutes/s. At the speed of 20 arc minutes/s, the variable speed drive starts feeding power to the motor that corresponds to the speed of 20 arc minutes/s and at a distance of 0.5 degree from target position, the power to the motor is cut off and electromagnetic brake is applied. The speed profile to variable speed drive is shown in Figure 4.

The GF drive and gripper hoist locks are driven by linear actuators consisting of single phase motor and ball screw mechanism. Control and power circuit are made in a motor control centre and interfaced with the real time computers for controlling the linear actuators.

I&C Design Features

a) All the operations of transfer arm / inclined fuel transfer machine can be carried out remotely

b) The scan cycle time of transfer arm real time computers is 200 milliseconds to achieve positioning of top structure of transfer arm to the desired accuracy

c) The scan cycle time of inclined fuel transfer machine real time computers is 150 milliseconds to achieve positioning of RSL rotation mechanism to the desired positioning accuracy

d) Hardwired operational/monitoring facility is provided in the operator panel for safe termination of incomplete operations, during failure of display station

e) The accuracy of the instrument is commensurate with the accuracy of the system requirement. Required accuracy of positioning is ± 3 mm for gripper hoist, ± 3 mm for guide tube and ± 4 arc minutes for transfer arm rotation mechanism

f) Redundant limit switches are used to sense the discrete positions of all the drives

g) Discrete position sensors are backed up by continuous position sensors

h) All the I&C equipments inclusive of sensors, cables, terminals in junction boxes, motors and real time computers are qualified to meet the applicable environmental conditions like temperature and humidity

i) Disagreement with the diverse redundant position sensor reading will lead to halting of transfer arm operation

j) Prevention of erroneous handling of absorber rods and fuel sub-assembly: Lowering and raising of absorber rods in the core is performed by respective absorber rod drive mechanisms where as replenishment of absorber rods is done using transfer arm during fuel handling.

To prevent inadvertent handling of fuel sub-assembly instead of absorber rods and vice versa, during fuel handling the following controls and interlocks are provided: Nominal level of absorber rods is 40 mm lower than the level of fuel sub-assembly in the core. The elevation corresponding to fuel sub-assembly is 22244 mm and the elevation corresponding to absorber rod level is 22204 mm. A key operated selector switch is provided in the operator panel to select the handling operation on either absorber rods or on fuel sub-assembly. During every operation of gripper hoist the real time computers check the position of selector switch and permit lowering as dictated by the selection. The real time computers will not allow the gripper hoist to reach the absorber rod elevation if the selection corresponds to fuel sub-assembly. If the selection is for handling of absorber rods, then gripping or releasing of sub-assembly is not permitted at the elevation corresponding to fuel sub-assembly.

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Young Researcher's FORUM

Corrosion Behaviour of Carbon Materials and Ceramic Coatings for Pyrochemical Reprocessing Applications

Shri Jagadeesh Sure obtained his M.Sc. (Materials Science) from Andhra University, Visakhapatnam. He joined IGCAR as a JRF in August 2008 and pursued his Ph.D. in HBNI, Mumbai under the guidance of Dr. U. Kamachi Mudali, Corrosion Science and Technology Group. The topic of his thesis is "Development of Ceramic and Composite Coatings on High Density Graphite Crucibles for Pyrochemical Reprocessing Applications". He has authored seven peer reviewed publications in International Journals, two more in the press and has attended about ten National/International Conferences and received best paper presentation awards on two occasions.

Fast Breeder Reactors with closed fuel cycle are an inevitable technology option to the energy security for India and a large scale deployment is proposed through metallic fuel reactors with emphasis on breeding gain. Pyrochemical reprocessing involving high temperature molten salt electrolytes is a leading technology for achieving the separation goals of the nuclear fuel cycle. Molten salt based pyrochemical process offers several advantages over the conventional PUREX process for the reprocessing of spent metallic fuels. The flowsheet planned for pyroprocessing of metallic fuel includes the important steps namely decladding, chopping of spent fuel, electrorefining, distillation of salt and consolidation of cathode product, casting the fuel and fabricating fresh fuel. The aggressive conditions encountered during these steps demand high corrosion resistant materials for molten chloride salt at high temperatures in the range 773-1573 K. The chloride salt requires to be purified to remove moisture and oxygen impurities before loading for the key processing step of electrorefining. The salt purifying system comprising of graphite crucible, liner and other parts should be compatible with the molten chloride salt at about 773 K in moisture and chlorine environments. Since the components in contact with molten chloride are likely to undergo severe corrosion at high temperatures, they need to be protected with corrosion resistant ceramic coatings to extend the service life of the components. Coating is also required for the graphite crucible used in the cathode processor to prevent the attack by molten salt (about 20 wt%) and uranium. The base material provides mechanical strength and the coating will provide protection from corrosion and chemical attack. The approach towards the study of corrosion behaviour of carbon materials, development of ceramic coatings on high density graphite and performance evaluation of the coatings for pyroprocessing applications is shown schematically as a flowchart in Figure 1. Corrosion of materials in molten salt depends on the composition, temperature, environment and exposure time. The specific type of corrosion of materials in molten salt at high temperature is known as 'hot corrosion'. Loss of material after corrosion test is attributed to the corrosion reaction and homogeneous or heterogeneous attack on the surface. Behaviour of materials in molten salt is investigated mainly by gravimetric method or weight change measurements and subsequent surface observation/characterization.

To establish pyrochemical reprocessing plants for reprocessing

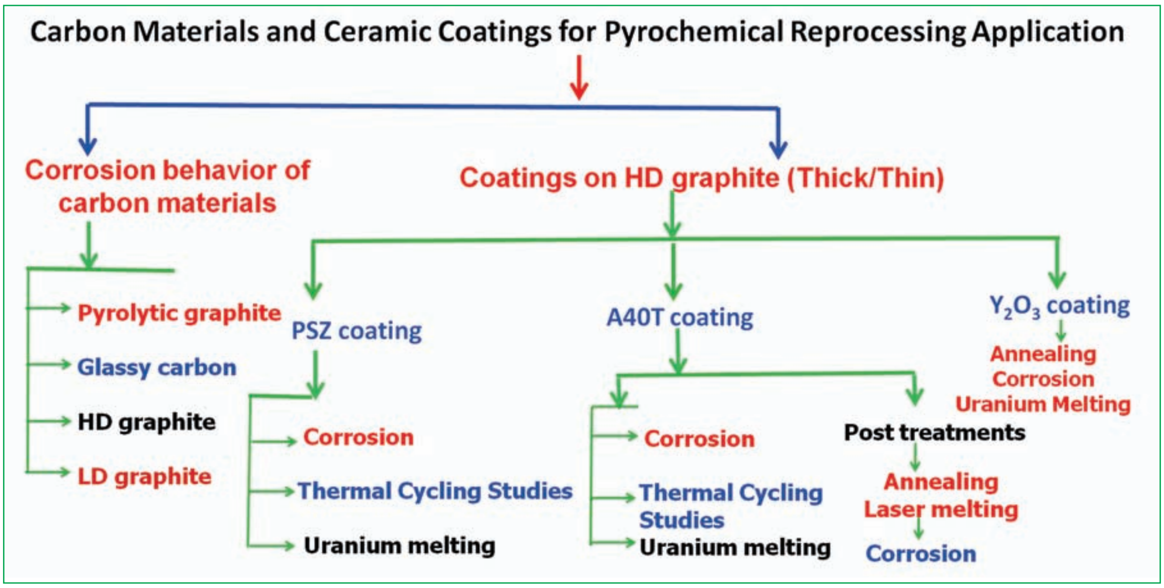

Figure 1: Flowchart showing the carbon materials investigated and ceramic coatings developed on high density graphite

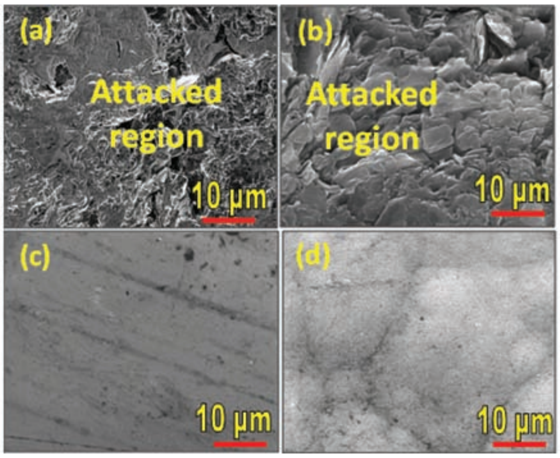

Figure 2: Microstructure of molten salt corrosion tested (a) low density graphite, (b) high density graphite, (c) glassy carbon and (d) pyrolytic graphite

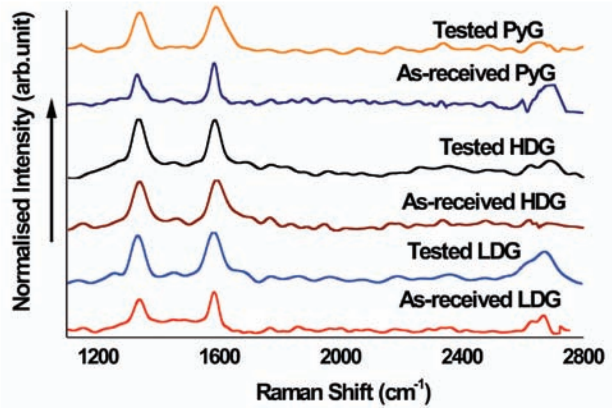

Figure 3: Raman spectra of as-received and molten salt exposed carbon materials

of spent metallic fuels of Fast Breeder Reactors with various unit operations, it is necessary to identify, develop and qualify reliable corrosion resistant materials and coatings for service in molten LiCl-KCl salt and molten uranium environment operating between 773 to 1573 K. Carbon based materials are proposed as candidate materials for various unit operations like vessels, liners and crucibles in pyrochemical reprocessing involving molten LiCl-KCl salt medium and molten uranium. The corrosion behaviour of carbon materials like low density graphite, glassy carbon, high density graphite and pyrolytic graphite was investigated and the performance of yttria stabilized zirconia, alumina-40 wt% titania (A40T) and yttria coatings on high density graphite was evaluated for their compatibility in molten salt medium and molten uranium and for deploying these coated materials for various applications in pyrochemical reprocessing.

Corrosion Behaviour of Carbon Materials

Carbon materials (low density graphite, glassy carbon, high density graphite and pyrolytic graphite) were exposed to molten LiCl-KCl salt at 873 K up to 2000 hours with continuous purging of ultra high pure argon gas throughout the experiment. Visual examination of these carbon materials after exposure to molten LiCl-KCl salt revealed the formation of pores on the surfaces of low and high density graphites. Weight gain was observed in low and high density graphites respectively; however, glassy carbon and pyrolytic graphite showed negligible weight loss after exposure to LiCl-KCl salt. The microstructures of molten salt corrosion tested low and high density graphites; glassy carbon and pyrolytic graphite are shown in Figure 2. The salt particles penetrated into the graphitic structure through the pores on the surface of low and high density graphites, resulting in the enhancement of absorption of molten salt, thereby gaining more weight. Penetration or absorption of molten salt into low density graphite was more compared to high density graphite, because of low density, high porosity and structural features accelerating the corrosion of low density graphite. Corrosion of carbon materials by molten salt involves one or more of the following mechanisms:

(1) formation of intercalation compounds,

(2) adherence and diffusion of salt into graphite and

(3) filling of surface pores by molten salt.

Owing to the non-wetting characteristics of glassy carbon by molten salt, no significant attack and initiation of pores was observed on the surface of glassy carbon after corrosion test for 2000 hours. Though the density of glassy carbon is quite low, its non-porous nature is due to the absence of large open pores and the presence of small closed pores of a few nanometer in size. As the pores are blind in nature, the salt particles could not penetrate into the glassy carbon. Pyrolytic graphite is prepared by the pyrolysis of methane gas and deposition on graphite substrates by chemical vapour deposition process; this method of preparation of pyrolytic graphite facilitates its improvement in the performance in molten chloride environment. The non-porous structure and highly preferred orientation of crystallites make the pyrolytic graphite chemically inert to molten LiCl–KCl salt. The nodular morphology that appeared on the corrosion tested sample was found to be similar to the as-deposited sample even after exposure for 2000 hours.

The absorption of molten salt into graphitic structures could proceed in different ways depending on the arrangement of graphite planes in the structure. The integrated intensity (I_D/I_G) ratio and band width of low density graphite, high density graphite and pyrolytic graphite, obtained from Raman spectra (Figure 3) of carbon materials confirmed the extent of disorder created by molten salt to be the least in pyrolytic graphite compared to low density graphite and high density graphite. Raman imaging confirmed that the molten salt induced a

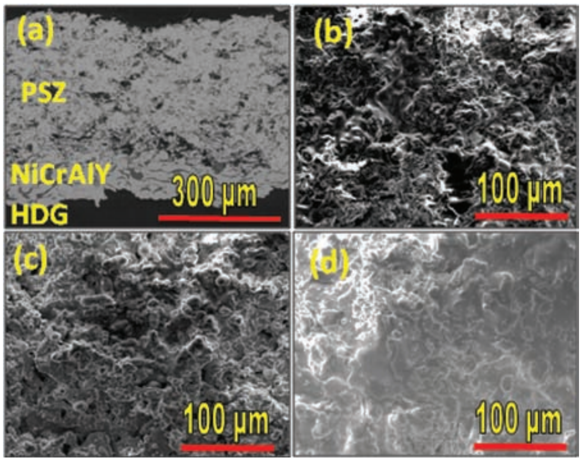

Figure 4: Partially stabilized zirconia coating on high density graphite (a) Cross section of as-sprayed coating; Surface morphology of (b) as- sprayed and (c) immersion tested coatings in molten salt and (d) after uranium melting

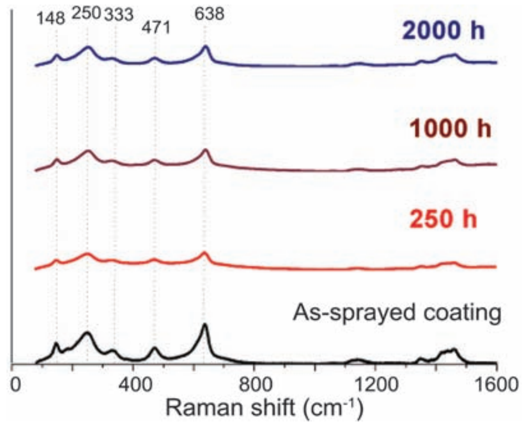

Figure 5: Raman spectra of as-sprayed and corrosion tested partially stabilized zirconia coatings

disorder in the microstructure of carbon materials and the D line distribution was less in the as-received carbon materials when compared to molten salt exposed ones. It is evident from the results that pyrolytic graphite has excellent corrosion resistance in LiCl–KCl salt at high temperatures under ultra high pure argon atmosphere. Hence, pyrolytic graphite material can be used in molten salt applications in the as-received condition. However, considering the commercial availability and cost factor, high density graphite is currently preferred for plant applications. The corrosion of high density graphite in molten salt indicated that a protective coating is essential for high density graphite to prevent its degradation in molten salt. Thus, protective, ceramic coatings have been developed on high density graphite for use as vessels and crucibles.

Partially Stabilized Zirconia (PSZ) coating on high density graphite

Thermal spray coating represents a group of processes in which plasma spray is one of the versatile and widely used processes. The application and demand of plasma spray coatings for nuclear fuel reprocessing is continuously increasing as a better option to overcome molten salt corrosion. Plasma spraying is used to apply a 250 µm thick partially stabilized zirconia coating over a metallic MCrAlY bond coat of 50 µm applied over the substrate. This thermal barrier coating provides protection from both heat and corrosion during service. Figure 4a shows the cross section of the as-sprayed NiCrAlY bond coat followed by 7-8 wt% yittria stabilized zirconia (YSZ) top coat on high density graphite. Top partially stabilized zirconia and bond coats exhibited laminar and splat morphology, which is the characteristic microstructural feature of plasma sprayed coatings. The purpose of the bond coat is to minimize the thermal expansion mismatch stress at the substrate-coating interface and to increase the adhesion strength of the coating. The partially stabilized zirconia coated high density graphite samples were immersion tested in molten LiCl-KCl salt at 873 K under ultra high pure argon atmosphere. The as-sprayed coating (Figure 4b) exhibited a typical splat morphology with pores, inter splat voids and microcracks. The surface morphology of corrosion tested partially stabilized zirconia coating in molten LiCl-KCl salt for 2000 hours (Figure 4c) showed no degradation or attack on the surface, even though the exposed surface showed weight gain due to salt deposition. The standard Gibb's free energy changes for the reaction of ZrO_2 and Y_2O_3 with chlorine for the formation of their respective chlorides at 873 K are 79 and 22 kJ/mol indicating that reaction between YSZ and chlorine is not feasible. Cross sectional examination of 2000 hours exposed coating revealed the formation of microcracks at the interface between bond coat and high density graphite due to the difference in thermal expansion coefficient. This observation indicates that a suitable bond coat with thermal expansion coefficient comparable to high density graphite is required to achieve good adhesion. Superior corrosion resistance provided by top partially stabilized zirconia coating to high density graphite even after 2000 hours of exposure to molten salt was due to the stabilized tetragonal zirconia phase confirmed by XRD and Raman analysis as shown in Figure 5. Small shots of uranium metal pieces placed on the coated sample was heated to 1623 K in ultra high pure argon atmosphere for melting of uranium and allowed to cool after soaking for 20 minutes. The surface morphology of yttria stabilized zirconia coating after uranium melting, shown in Figure 4d also exhibited splat morphology and EDX analysis did not show any peak corresponding to uranium on the surface. Phase analysis by XRD confirmed the absence of any reaction product on the surface of the coating after uranium melting and only tetragonal phase of partially stabilized zirconia could be identified.

In pyrochemical reprocessing, the process steps are batch mode. The loading and unloading of salts and temperature excursions during operation may lead to build up of thermal strains associated with cracking and spallation of coating during prolonged service. Hence, it is necessary to study the effect of temperature on the coated materials. Thermal cycling studies of the coated samples were conducted in an automated furnace at 873 and 1023 K in vacuum sealed quartz ampoules to avoid the oxidation of coating and to simulate the pyroprocessing conditions. The coated high density graphite samples were subjected to 200 thermal cycles. After 100 thermal cycles at 873 and 1023 K, visual examination of the coated samples did not show any coating spallation as could be seen in Figure 6. Surface morphology by SEM did not reveal any significant change; however, cracks were generated on the splat structures due to the relief of thermal induced stresses from the coating during thermal cycling. X-ray diffraction and Raman spectra studies showed only tetragonal phase irrespective of temperature excursions even after 100 cycles recorded on the surface of the yttria stabilized zirconia coating. These studies uphold the choice of yttria stabilized zirconia coatings on high density graphite material to protect it from hot corrosion in chloride medium.

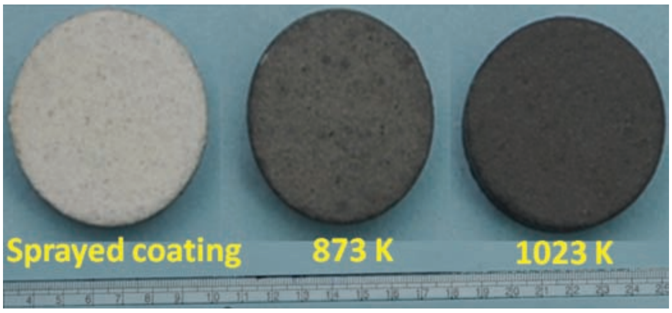

Figure 6: Visual examination of partially stabilized zirconia coating on high density graphite before and after thermal cycling

Alumina-40wt% titania coating on high density graphite

High purity alumina coatings are widely used for insulating metals and alloys. Alumina composites rather than pure Al_2O_3 have certain advantages. Titania has a melting point lower than alumina and it effectively binds alumina grains, contribute to high density, diminishing the porosity and increase the fracture toughness of coating. Hence, alumina-40 wt% titania (A40T) coating was plasma sprayed on high density graphite, with and without the bond coat of Cr_3C_2-NiCr. The microstructural features of the corrosion tested A40T coatings showed better corrosion behaviour up to 500 hours in molten LiCl-KCl salt at 873 K. The values of 103 and 62 kJ/mol respectively for the standard Gibb's free energy of reaction for alumina and titania with chlorine at 873 K indicate that these oxides possess good thermodynamic stability in chlorine contained environment. The surface of the A40T coated samples exposed to molten salt up to 500 hours showed the formation of cracks and salt deposits, while spallation of the coating occurred after 1000 and 2000 hours exposure. The A40T coating with the bond coat of Cr_3C_2-NiCr exposed to molten LiCl-KCl salt for 2000 hours revealed that the complete spallation of top ceramic coat was due to poor adhesion between the bond coat and A40T as Cr_3C_2-NiCr bond coat subsequently got oxidized. The phases present in the as-sprayed coating (β-Al_2TiO_5, γ-Al_2O_3, R-TiO_2 and α-Al_2O_3) remained in the spalled coating after corrosion test in molten salt for 1000 hours. This study suggested that an improvement in A40T coating adhesion to high density graphite is required for long term exposure to molten salt. The performance of A40T coating can be improved by post spray treatments. The surface of plasma sprayed A40T coating was thus, modified by vacuum annealing and laser melting post treatments. Pulsed Nd:YAG laser was used for the melting of plasma sprayed A40T coatings to consolidate and generate dense layer over the surface. The surface homogeneity of the coating improved with laser melting as the pulse energy increased from 320 to 400 mJ (Figures 7a and b). The segmented crack network formed on the coating after laser melting could be due to the shrinkage and relaxation of residual stresses during the cooling of molten ceramic coating to room temperature. The lamellar morphology of plasma sprayed A40T coating on the cross section

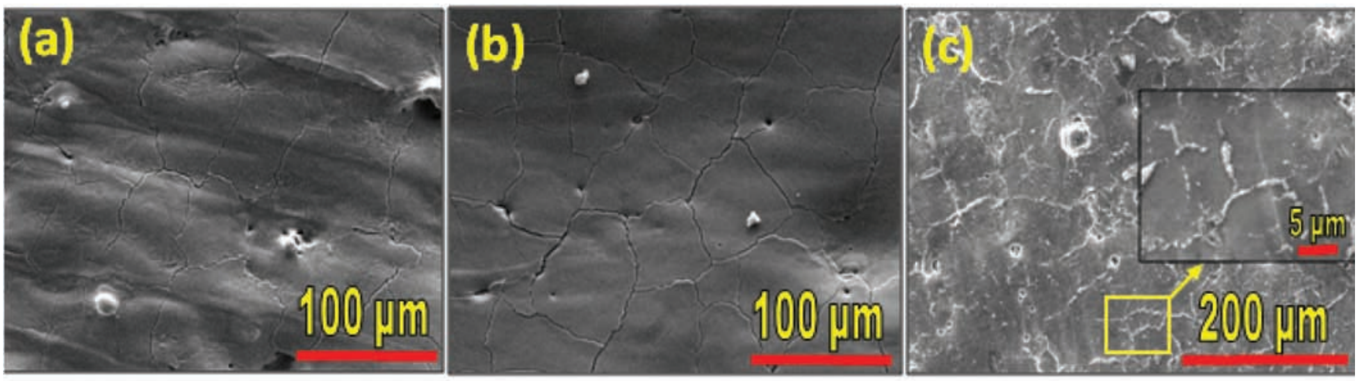

Figure 7: Surface morphology of laser melted A40T coating with pulse energy of (a) 320 and (b) 400 mJ and (c) surface morphology of coating after corrosion testing

got consolidated after laser melting indicating that densification occurred only within a few micron thickness of the coating. α-Al_2O_3 phase present in the as-received powder was transformed to metastable γ-Al_2O_3 during spraying and it changed to stable α-Al_2O_3 again by post treatments. Laser melted coatings were found to have β-Al_2TiO_5 as the predominant phase and the coating melted with higher energy/power exhibited high hardness and low roughness. The SEM micrograph of laser melted A40T coating after corrosion testing in molten LiCl-KCl salt for 24 hours is shown in Figure 7c. The cracks formed in the coating during laser melting were filled with molten salt after corrosion test. Salt penetration was less in the coatings melted with the laser energy of 400 mJ and no macroscale damage was observed. The external dense layer generated by laser melting restrained the penetration of the molten salt into the coating to a certain extent. Small shots of uranium metal were melted on A40T coated high density graphite at 1623 K. Uranium metal was found to be sticking on the coating and it was difficult to remove the metal. The A40T coatings were also observed to spall off from some of the high density graphite substrates after melting experiments due to poor adhesion to high density graphite. This indicated the scope for further improvement of the A40T coating.

Pulsed laser deposited Y_2O_3 coating on high density graphite

Pulsed laser deposition is an attractive technique for deposition of oxide coatings and also known for its ability to grow adherent and crystalline thin films/coatings retaining the stoichiometry of the target. In an attempt made to deposit Y_2O_3 coating on high density graphite by pulsed laser deposition process, the thickness was found to be 2 μm from profilometry. Y_2O_3 coated high density graphite samples exposed to molten LiCl-KCl salt at 873 K for three hours under ultra high pure argon atmosphere were characterized to understand the corrosion behaviour. The spherical morphology of the oxide particles and agglomeration of these particles on high density graphite could be attributed to the process conditions for deposition. Agglomeration morphology of nano Y_2O_3 particles was confirmed by AFM analysis. The resistance of Y_2O_3 towards molten salt attack is due to the thermal stability at high temperature and its inertness to aggressive chemical attack by molten metal and salt. After vacuum annealing at 1373 K, no appreciable change in the morphology and particle growth was observed. Presence of cubic phase of Y_2O_3 on the deposited coating was confirmed by XRD and Raman studies. Uranium melting experiments were conducted on Y_2O_3 coated high density graphite crucibles at 1623 K. Figure 8 shows the visual examination of Y_2O_3 coating before and after uranium melting. Phase identification by XRD revealed only cubic Y_2O_3 phase and peaks corresponding to uranium were absent. The corrosion tests performed on Y_2O_3 coating confirmed the better compatibility of yttria with high density graphite and providing protection to high density graphite from the attack by molten chloride salt as well as molten uranium. The positive values for the standard Gibbs free energy change for the reaction of Y_2O_3 with Cl_2 and uranium from 273 to 1800 K also corroborate that Y_2O_3 is thermodynamically stable in chlorine and with molten uranium. However, molten salt experiments for long durations and with molten uranium under conditions simulating the cathode processor environment are required to substantiate these conclusions and to evaluate the performance of Y_2O_3 coating.

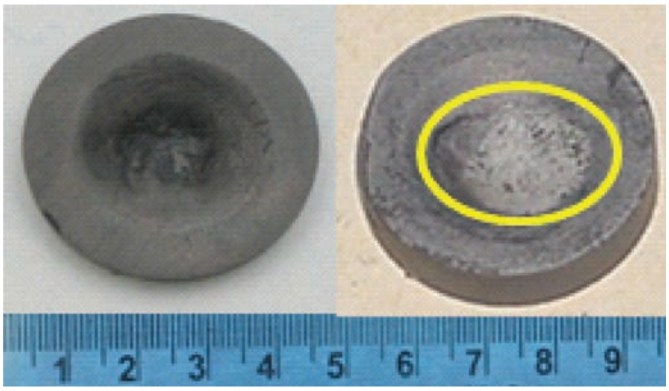

Figure 8: Visual examination of Y_2O_3 coating on high density graphite before and after uranium melting

Corrosion behaviour of the carbon materials exposed to molten LiCl-KCl salt for 2000 hours at 873 K showed that the corrosion resistance of carbon materials follows the order: low density graphite < high density graphite < glassy carbon< pyrolytic graphite. Degradation of partially stabilized zirconia coated high density graphite was insignificant after testing in molten salt at 873 K. Uranium melting studies indicated that no reaction had occurred between uranium and partially stabilized zirconia coating at 1623 K, thereby upholding the choice of yttria stabilized zirconia coated high density graphite crucible for cathode processor application. The adhesion strength of Al_2O_3-40 wt% TiO_2 coating on high density graphite substrate was poor in all the tested conditions i.e. in molten LiCl-KCl salt as well as in uranium melting test. Post treatments (vacuum annealing and laser melting) for surface modification yielded marginal improvement in the corrosion resistance of Al_2O_3-40 wt% TiO_2 coatings to molten salt and laser melting with high pulse energy improved the properties of the coatings. The yttria stabilized zirconia coated high density graphite performed well even after thermal cycling at 873 and 1023 K. Evaluating the combined effect of molten salt and uranium at and above 1573 K on ceramic coated high density graphite is required to complete this study.

Reported by Jagadeesh Sure
Corrosion Science and Technology Group

New's and Events

Inauguration of Integrated Facility for Fusion Reactor Materials

January 28, 2013

Shri S.C. Chetal, the then Director, IGCAR and Prof. D.Bora, Director, IPR, cutting the ribbon to mark the inauguration of IFFRM building

IGCAR and Institute for Plasma Research (IPR), Gandhinagar have a memorandum of understanding for collaboration towards development of materials, fabrication technologies, NDT techniques and design of components along with setting up of required experimental facilities for the ITER fusion reactor project. The specific responsibilities identified during the initial phase of the collaboration include

(a) development of Indian Reduced Activation Ferritic Martensitic (RAFM) steel for ITER Test Blanket Module (TBM)

(b) development of fabrication technologies for RAFM steel and

(c) development of non-destructive evaluation methodologies for test blanket module programme.

India is a partner in the international R&D efforts to harness fusion energy through its participation in the ITER project. ITER is the experimental Tokamak nuclear fusion reactor and it is presently under construction at Cadarache in France. The ITER project aims to make the long-awaited transition from experimental studies of plasma physics to full-scale electricity-producing fusion power plant. The project is funded and run by seven member entities, namely, the European Union, India, Japan, China, Russia, South Korea and the United States. ITER has been designed to produce 500 MWe of output power for 50 MWe of input power. The machine is expected to demonstrate the principle of producing more energy from the fusion process than that is used to initiate it, something that has not yet been achieved so far. The first commercial demonstration fusion power plant, named DEMO, is proposed to follow subsequent to the ITER project, to bring fusion energy to the commercial market.

As part of the international collaboration, different countries will design and fabricate test blanket modules of various designs and it will be tested in the ITER, for which specific ports are assigned to each member country. The development of structural materials for test blanket module that faces the high temperature plasma, is considered as one of the main challenges for the realization of fusion power plant. The test blanket module material shall satisfy the requirements of adequate resistance to high energy neutron irradiation, acceptable physical and mechanical properties at high temperatures, low ductile to brittle transition temperature, corrosion resistance to ensure compatibility with the breeding materials, and above all, produce very low levels of induced radioactivity.

Reduced activation ferritic-martensitic steels (RAFM) having 9-12 wt% chromium are presently considered as the main candidate material for the test blanket modules to be tested in ITER by the different participating countries. Internationally developed RAFM steels have tungsten in the range 1–2 wt% and tantalum in the range 0.02–0.18 wt% and very low levels of residual elements that can transmute to long half-life isotopes. The RAFM steel for Indian test blanket module, and the associated joining technologies are being developed jointly by IGCAR and IPR in collaboration with International Advanced

Dr. P. R. Vasudeva Rao, Director, IGCAR, Shri S.C. Chetal, the then Director, IGCAR, Dr. T.Jayakumar, Director, MMG, IGCAR, Prof. D.Bora, Director, IPR, Shri Rajendra Kumar, IPR and other invitees arriving for the inaugural function

Research Centre for Powder Metallurgy and New Materials (ARCI), Defence Metallurgical Research Laboratory (DMRL), Defence Research & Development Laboratory (DRDL) and Mishra Dhatu Nigam Limited (MIDHANI).

In order to develop an Indian version of RAFM steel for test blanket module applications, by optimising the chemical composition and processing steps and qualifying the material in terms of microstructure, mechanical properties and to develop the appropriate fabrication technologies and inspection, a dedicated materials development and testing facility, named as Integrated Facility for Fusion Reactor Materials (IFFRM) is planned at IGCAR, with the support of IPR. IFFRM, when fully commissioned, will have state-of-the-art testing facilities for characterizing microstructures and evaluation of mechanical properties of materials, non-destructive testing and evaluation, and fabrication technologies. The IFFRM building along with a few laboratories was inaugurated on January 28, 2013, by Shri S. C. Chetal, the then Director of IGCAR in the presence of Prof. D. Bora, Director, IPR. Several senior scientists from IPR and many colleagues from IGCAR participated in the function. The IPR team included Shri E. Rajendra Kumar, Head, Test Blanket Module Division, and Dr. Sishir Deshpande, Project Director, ITER India. Dr. P. R. Vasudeva Rao, Director, IGCAR, Shri P. V. Kumar, Project Director, FRFCF, Dr. T. Jayakumar, Director, Metallurgy & Materials Group, Mr. Sivathanu Pillai, Associate Director, CEG and many colleagues from Metallurgy & Materials Group as well as Engineering Services Group attended the function. Prof. P.K. Kaw, former Director, IPR, who was instrumental for this fruitful collaboration between IGCAR and IPR, could not attend the function due to prior commitments. His message which was read out by Prof. D. Bora, is reproduced below.

"Shri Chetal and other colleagues from IGCAR and IPR, I convey my greetings to all of you on the occasion of this IGCAR-IPR Collaboration meeting and regret that I am unable to personally participate because of prior engagements with a team from LIGO project, USA. IGCAR- IPR Collaboration on fusion reactor materials has come a long way since its formal inception a few years ago in connection with the TBM and ITER Projects. Director, IGCAR has played a critical role in making this collaboration a great success. I am especially grateful to you, Shri Chetal, for taking a keen and active personal interest in the IPR Projects and ensuring they are completed with high quality and within acceptable cost and schedule. I look forward to continued technical interaction of IPR teams with you, even after you complete your tenure at IGCAR. The inauguration of the IFFRM laboratory buildings marks the reaching of an important milestone in our collaborative programs. Heartiest congratulations to all on this happy occasion.

- P K Kaw"

Speakers at the function sincerely thanked the services rendered by Civil, Air Conditioning and Electrical Divisions of IGCAR for the timely completion of the IFFRM building in spite of several challenges, To mark the occasion, tree saplings were planted on the eastern side of the IFFRM building.

Extensive studies have been done at IGCAR towards developing the Indian RAFM steel and a steel with optimized composition, named as IN-RAFM steel has been developed. Poster presentations were made highlighting the extensive R&D work so far carried out in the development of IN-RAFM steel and the future plans towards development of the associated fabrication and NDT technologies. R&D studies have also been initiated for the development of other fusion reactor materials including oxide dispersion strengthened (ODS)-RAFM steel.

Reported by T.Jayakumar and M.D.Mathew, MMG

Conference and Meeting Highlights

24th Annual General Meeting of Materials Research Society of India
Kalpakkam
February 11-13, 2013

Delegates of the MRSI-AGM-2013 at Kalpakkam

The 24th Annual General Meeting of the Materials Research Society of India (MRSI) was held at the Indira Gandhi Centre for Atomic Research, Kalpakkam, during February 11-13, 2013. Prof. C. N. R. Rao, National Research Professor & Linus Pauling Research Professor, JNCASR, Bangalore addressed the gathering of over three hundred Materials Scientists from all over the Country.

The Annual General Meeting of the Materials Research Society of India, included the following honour lectures: (i) International Materials Science and Technology Award Lecture by Prof. Richard Friend, University of Cambridge; (ii) Distinguished Materials Scientist of the year award Lecture by Dr. T. Ramasami, Secretary, Department of Science and Technology; (iii) Materials Research Society of India Distinguished Lectureship Award Lecture by Dr. Suresh Das, National Institute for Interdisciplinary Science and Technology, Trivandrum and (iv) Prof. C.N.R. Rao Prize lecture in Advanced Materials by Prof. Milan Sanyal, Saha Institute of Nuclear Physics. The MRSI-ICSC Superconductivity and Materials Science Annual Prize lectures were delivered by Dr. R. Muraleedharan, SSPL and Shri M.P. Janawadkar, IGCAR and there were fourteen Materials Research Society of India Medal lectures at the Annual General Meeting. About one hundred and fifty contributed poster papers covering the latest research on various aspects of materials science were presented at the meeting. A special session on Exotic Materials under the Asia Pacific Academy of Materials (APAM), was conducted by Prof. O. N. Srivastava, Banaras Hindu University, during the Annual General Meet.

As a part of the Annual General Meeting of the Materials Research Society of India, a theme symposium on "Advanced Materials for Energy Applications" was conducted, in which lectures were delivered by Dr. S. Banerjee, DAE Homi Bhabha Chair Professor, Mumbai, Dr. Baldev Raj, President-Research, PSG Institutions, Coimbatore, Dr. R. C. Budhani, NPL, New Delhi and Prof. Satish Vitta, Indian Institute of Technology, Mumbai. A special evening talk on " The Development of Solar Energy in India" was delivered by Dr. Anil Kakodkar, DAE Homi Bhabha Chair Professor, Mumbai.

The Annual General Meeting of the Materials Research Society of India, at Kalpakkam, that provided a rich fare of excellent talks on various facets of Materials Science, was widely appreciated.

Reported by G. Amarendra
Convenor, MRSI-AGM

9th CEA-IGCAR Annual Meeting on Liquid Metal Fast Reactor Safety
March 18-21, 2013

CEA Delegates with Dr. P. R. Vasudeva Rao, Director, IGCAR and senior colleagues of the Centre

Under the continuing Indo-French Collaborative activities, 9th CEA-IGCAR Annual meeting on Fast Reactor Safety was organized by IGCAR during March 18-21, 2013. Thirteen French and thirty seven Indian delegates (from IGCAR, BHAVINI & AERB) participated in the seminar. Dr. P. R. Vasudeva Rao, Director, IGCAR inaugurated the seminar and lucidly presented the overall updates of the CEA-IGCAR collaborations since 2005. Two topical seminars dedicated to safety and materials in support of LMFR safety were held on March 18-19, 2013, respectively. A total of about six presentations were made on status of FBTR operation, PFBR construction and commissioning status, PHENIX progress report: decommissioning and core flowering test, superphenix decommissioning, ASTRID project overview and design and R&D status of FBR 1&2. A detailed review of the status of collaborative works in the domains of sodium aerosols, electrochemical hydrogen meter on sodium facility, sodium leak detector, code calculations on impingement wastage for 9Cr-1Mo steam generator tubes, mesoscale and microscale atmospheric dispersion, studies on fluid structure interaction, characterization of gas content in sodium, severe accident in sodium-cooled fast reactor, oxide (Phenix pin) and carbide (FBTR pin) fuels etc. Further, the areas for future collaborative works such as Ferro-boron as shielding material for Fast Reactors, measurement of oxygen activity in sodium, Molten Fuel Coolant Interaction Modeling under severe accident scenario etc. were identified. This was followed by a meeting on review of sodium loop for irradiation of multiple samples at high temperatures towards using in JHR on March 22, 2013. Four French delegates and fourteen Indian delegates participated in the meeting. The introductory remarks were presented by Dr. P. R. Vasudeva Rao, Director, IGCAR and Dr. Giles Bignan, JHR user interface manager. Dr. P. R. Vasudeva Rao, Director, IGCAR highlighted the overall activities of the Centre and construction status of PFBR and Dr. Giles brought out the details, objectives and current status of JHR. There were three technical presentations and the CEA team then visited the test facility, which is in commissioning stage.

Reported by P. Chellapandi, RDG

Visit of Dignitaries

Delegates from Czech Republic with Dr. P. R. Vasudeva Rao, Director, IGCAR, Dr. Prabhat Kumar, CMD, BHAVINI and senior colleagues of the Centre

His Excellency Mr. Vaclav Bartuska, Ambassador at Large for Energy Security of the Czech Republic, His Excellency Mr. Miloslav Stasek, Ambassador of the Czech Republic to India visited the Centre on January 7, 2013. After a meeting with Director, IGCAR and senior colleagues of the Department, the delegation visited the Fast Breeder Test Reactor & KAMINI Reactor, Hot Cells and Non-Destructive Evaluation Division, facilities in Fast Reactor Technology Group and Construction site of Prototype Fast Breeder Reactor.


Dr. S. Sivaram from National Chemical Laboratory, Pune delivering the Bhatnagar Memorial Lecture

Dr. S. Sivaram from National Chemical Laboratory, Pune delivered the Bhatnagar Memorial Lecture on "Publicly Funded Research Institutions and the Legacy of Sir Shanti Swarup Bhatnagar" organized by Society for Advancement of Chemical Sciences and Education during his visit to the Centre on February 21, 2013.

Delegates from ASEAN countries visited the Centre on February 22, 2013. During the meeting with Dr. P. R. Vasudeva Rao, Director, IGCAR and senior colleagues, the delegates were briefed about the R&D activities of IGCAR by Dr. M. Sai Baba, Associate Director, Resources Management Group. After the meeting, the delegation visited the Fast Breeder Test Reactor and Madras Atomic Power Station.

Delegates from ASEAN countries with Dr. P. R. Vasudeva Rao, Director, IGCAR and senior colleagues of the Centre

Forthcoming Meeting and Conference

Recent Advances in Information Technology (READIT)

Scientific Information Resource Division (SIRD) in collaboration with Madras Library Association – Kalpakkam Chapter(MALA-KC) is organizing the 9th National Conference on the theme "Towards a Semantic Digital Library Infrastructure" during August 29-30, 2013 at IGCAR, Kalpakkam. This Conference forms a part of the series "Recent Advances in Information Technology (READIT)". This READIT series is being conducted from 1995 onwards. The previous Conferences were well received by professionals engaged in IT and Library & Information services and Academic institutions. The Conference will be preceded by a one-day Tutorial on " Creating Content Portals " on August 28, 2013.

The Conference will have invited talks as well as contributed papers on the following sub-themes:

- Virtualized Digital Library Infrastructure
- Cloud Computing Techniques
- E-books & Enabling Architecture
- Semantic Metadata Creation & Retrieval
- Knowledge Dissemination Techniques
- The changing role of Library

Contributed papers on any of the above mentioned sub-topics are invited.

There will be also a separate session for the presentations of research scholars and students in this domain.

Address for correspondence

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Awards & Honours

Dr. A. K. Tyagi, MSG has received the "Eminent Mass Spectroscopist Award - 2013" from Indian society for Mass Spectrometry (ISMAS) in recognition of his outstanding contributions in the area of Secondary Ion Mass Spectrometry.

Shri Jagadeesh Sure has been awarded the "Swarna Jayanthi Endowment " award by the Indian Institute of Metals for attending the International Conference on "Technological Advances of Thin Films and Surface Coatings" at Singapore Management University, Singapore

IGCAR has won the AERB's Fire safety award for the Year 2012

Best Paper/Poster Award

Formation of Delta Ferrite in the Weld Metal of 9-12Cr Steels
Shri K.V. Sajunath from GSO, Shri Chitta Ranjan Das, Dr. Shaju K. Albert, Shri S.Raju and Dr. A. K. Bhaduri from MMG
National Welding Seminar-2011, Bhilai Steel Plant , Bhilai, December 15-17, 2011
D & H Secheron Best Presentation Award -2012
H.D. Govindraj Memorial Research Award-2012 for Second Best Research Paper

Enhanced Localized Corrosion Resistance of Modified 9Cr - 1Mo Steel by Mesoporous Silica based Self Healing Coatings
Shri C. Arunchandran, Dr. S. Ramya, Dr. R.P. George and Dr. U. Kamachi Mudali from MMG
International Corrosion Prevention Symposium for Research Scholars (CORSYM-2013), Chennai, February 28 - March 02, 2013 organized by NIGIS, India and NACE, East Asia Pacific Area
Best Oral Presentation Award

Corrosion Behaviour of Carbon Materials and Development of Ceramic Coatings on High Density Graphite for Molten Salt Application
Shri Jagadeesh Sure, Dr. C. Mallika and Dr. U. Kamachi Mudali from MMG
International Corrosion Prevention Symposium for Research Scholars (CORSYM-2013), Chennai, February 28 - March 02, 2013 organized by NIGIS, India and NACE, East Asia Pacific Area
Best Poster Presentation Award

Fabrication of Self-Organized Titania Nanotube arrays and its Corrosion Resistance in Hank's Solution
Dr. U. Kamachi Mudali and Dr. N. Rajendran from RpG and Dr. K. Indira from Anna University
International Corrosion Prevention Symposium for Research Scholars (CORSYM-2013), Chennai, February 28 - March 02, 2013 organized by NIGIS, India and NACE, East Asia Pacific Area
Best Poster Presentation Award

Alternate Applications of Anodic/Cathodic Potentials as a Non-conventional Tool to Control Bacterial Adhesion on Titanium
Ms. S. D. Ruth Nithila, Dr. R.P. George, Dr. U. Kamachi Mudali and Dr. N. Parvathavarthini from MMG and Dr. R.K. Dayal formerly from MMG
International Corrosion Prevention Symposium for Research Scholars (CORSYM-2013), Chennai, February 28 - March 02, 2013 organized by NIGIS, India and NACE, East Asia Pacific Area
Best Poster Presentation Award

Homage to Shri S. R. Paranjpe

Shri Shrikant Ramakrishna Paranjpe former Director of IGCAR passed away on **March 23, 2013**. Shri S.R.Paranjpe fondly called the father of Indian Fast Reactor Programme, was born on **November 10, 1932**. After obtaining his Bachelor degree in Chemical Engineering, he joined the Department of Atomic Energy in the year 1955 and worked in Bhabha Atomic Research Centre, Mumbai. He headed the Fast Reactor Section at BARC in the year 1965 and initiated the preliminary design of a 10 MWe experimental fast reactor. In June 1971, he shifted to Indira Gandhi Centre for Atomic Research (then Reactor Research Centre), Kalpakkam as Principal Design Engineer (Head, Design Group) for executing the FBR programme. Shri S.R. Paranjpe, along with late Shri P.R. Roy under the Chairmanship of Dr. Raja Ramana boldly decided the use of mixed carbide fuel of unique composition as driver for FBTR, when there was unprecedented hindrance in the fuel supply to the nation due to Peaceful Nuclear Explosion in 1974. He played a key role in obtaining all the safety clearances for the test reactor and was well known for giving spot verdict for any technical issue to be resolved, by performing hand calculations or mental arithmetic. Shri S.R. paranjpe guided the working group in the preparation of Detailed Project Report for PFBR and initiated a programme for testing PFBR MOX fuel composition with ^{233}U and ^{239}Pu in FBTR. In short he was instrumental in setting up the Fast Breeder Test Reactor as well as several associated facilities which has made this Centre a Centre of excellence in the field of sodium cooled fast reactors. He served as the Director of IGCAR, Kalpakkam from 1990 till 1992.

Through his dedication, hard work and inspiring leadership, he built a dedicated team of scientists and engineers to pursue the fast reactor programme in India. The Centre today owes its existence and growth to late Shri Paranjpe, who was one of the founders of the erstwhile Reactor Research Centre in 1971.

Shri S.R.Paranjpe was a recipient of INS Homi Bhabha Life Time Achievement Award. He was a simple, humble and compassionate human being, who started the Homoeopathic Association of Kalpakkam to provide medical assistance to the poor people around.

In the passing away of Shri S. R. Paranjpe the nation has lost a patriotic scientist whose every breath was for the growth and well being of our nation in general and Indian Nuclear Programme in particular and the Centre has lost a well wisher and guide.

Shri S.R. Paranjpe had made immense and valuable contributions to Indian Fast Reactor Program. A man of strong convictions with a Gandhian outlook, led a team in a high-tech area of great relevance and significance to India. Shri Paranjpe inspired, mentored and created an environment of continuous learning for large members of his young team. Nothing was impossible for him. To discuss on a complex problem, if required, to start with, he would subdivide it into simple modules and make approximations and then work on finer aspects on eliminating the same. He had very ably demonstrated a rare expertise and flair for both science and engineering. His list of contributions to this Centre is very exhaustive. He made contributions to FBTR: from design in collaboration with France, obtaining safety clearances, construction and operation towards fulfilling the basic objectives of the reactor. For PFBR, his contributions included both conceptual and detailed design, manufacturing technology, road map for R&D and preparation of Detailed Project Report of 4-loop design in 1989 with very little contribution from his colleagues. His justifiable passion for metal fuel development from the lowest doubling time considerations, among various fuel options in the Indian scenario of limited uranium resources, has been adopted commercialization, in a time bound manner. The best way to put his soul in peace is to carry out the mission of metal fuel development in this Centre with zeal.

Personally he was a hero for me and had left a deep impression forever. I must confess that though he had a image of a tough person, he had a very soft corner for me and encouraged me to take up challenging tasks. He inspired my career and because of his enormous trust and confidence, he made me learn many subjects including design codes and materials technology which have been very useful in discharging my professional responsibilities. It is very appropriate to mention here and acknowledge that whatever I know today, the credit goes to my Guru, Shri Paranjpe.

Shri S. C. Chetal, Former Director, IGCAR

S. R. Paranjpe, was a legend, during his lifetime, in the domain of science and technology of sodium cooled fast reactors. He had firm grip on the three stages of nuclear energy programme in India; their roles, time lines and challenges.

S. R. Paranjpe, was steering the fast reactor programme, at the time of stringent denial and control regimes for India after nuclear explosions of 1974. These denials were especially stringent for domains of fast breeder reactors and closed fuel cycle, due to the perception by some of the Nuclear Supplier Group countries that India is pursuing fast breeder reactors as plutonium laundry machines combined with recycling, for making atomic weapons and stock piling of large quantities of weapon grade plutonium.

However, India, through the three stage programme, as envisaged by Homi Bhabha, well before nuclear explosions of 1974 and consequent restrictions, had realized the importance of fast breeder reactors, with closed fuel cycle, to achieve energy sustainability, security and launching a large thorium based nuclear energy programme. In spite of this wide variance in the perspectives & Indian realities, S. R. Paranjpe, was deeply respected worldwide for his expertise and clear independent thinking. This stature was achieved even though S. R. Paranjpe had no big awards, fellowships of academies a large number of publications, to his credit. He was recognised for his clarity and convictions, as I found through my discussion with peers and leaders of national and international programmes, during my responsibilities at Indira Gandhi Centre of Atomic Research. When I interacted with national and international experts of high reputation, I realized and appreciated the fact that his acceptance was due to his in-depth understanding and robust analysis of complete spectrum of science and technology of fast spectrum reactors with closed fuel cycle. It is also to be noted that the programme of Fast Reactors Science and Technology was at a nascent stage at that time. Thus, all the more, it was a remarkable success of S. R. Paranjpe's expertise with high ethics that won him appreciation and long lasting friendships.

I experienced that his approaches were inclusive and covered fundamental aspects to details of technology. He was ready to engage and challenge any specialist to either convince or get convinced based on merit of the discussion. You could not win argument and get a decision from him, based on superficial arguments or quoting from literature, without firm basis or clarity of the arguments.

He was a practicing Gandhian Director of the Centre. At the time of financial constraints in the country, he travelled by bus or train rather than using car or air travel.

He was extremely conscious of spending public money. However, he did not hesitate to sanction large sums of money, once convinced about usefulness of the proposal. He was close to some, not due to associations but because of specialties of the assignments. But, you could always be sure to get an honest and just decision from him.

He could be seen travelling by bicycle in township and villages, for his personal work. He was committed and convinced about Homeopathic system of medicine. He trained and mentored many interested persons from Kalpakkam in Homeopathy. He served residents of townships and villages, using homeopathic treatments, with dedication and faith, in selfless service to the society. He held Dr. Vikram Sarabhai, in high esteem and considered him as his icon and inspiration.

I was delighted when my recommendation, in my capacity as Director, Indira Gandhi Centre for Atomic Research, was accepted to award him Life Time Achievement Award of Department of Atomic Energy. Up to his almost last day on this earth, he held unwavering faith in sodium cooled and metal fuelled fast breeder reactors and closing the fuel cycle with pyrometallurgy route for high breeding to realize faster face of harnessing nuclear energy, in an economical, sustainable and eco-friendly manner.

I have not experienced such a true Gandhian Director of high competence, who was committed to his profession and ethical values without being tempted by positions of power and the world of recognitions.

I pray to Divine for peace of the departed soul of S. R. Paranjpe and also sincerely hope that his exemplary consciousness, competence, commitment, simplicity and ethical values, shall continue to motivate colleagues in Indira Gandhi Centre for Atomic Research, Kalpakkam Campus of DAE, S&T community of DAE and India.

Dr. Baldev Raj, Former Director, IGCAR

Lagerstroemia indica (Indian Lilac)

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