IGC Newsletter

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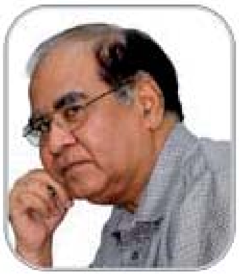
From the Director's Desk

IGCAR-IIT Madras Collaborations



"It is possible to develop atomic energy through basic, applied and developmental research in islands largely isolated from the rest of the country, but large-scale applications for the benefit of the nation cannot be undertaken in isolation"

- Vikram Sarabhai

The demand for energy would increase substantially in line with the envisaged GDP growth in the coming decades. While it is an accepted perspective in India that all the available sources of energy should be developed and deployed to meet the growing demand, the adverse impact of the growth on the climate change, consideration of economics are important for sustainable development. Nuclear energy has a proven track record of providing clean and competitive energy in a publicly acceptable manner. Taking into consideration the increased multitude nature of energy resources and to mitigate climate change, the world is ushering in a renaissance of Nuclear Energy. Different countries have come out with plans, specific to their requirements, towards commissioning of nuclear plants and are at various stages of progress. Fast reactors with closed fuel cycle as a sustainable energy source is the technology being pursued by our country.

In an FBR with 40% thermal efficiency, one gram of heavy metal can generate 120 kWd electrical power. About 60 grams of natural uranium is required for PHWR and about 1.5 tonnes of coal is required for fossil plant to generate the equivalent energy. To harness this potential in FBR, advanced core structural material to withstand the effects of high irradiation and an efficient coolant (to extract the high heat generated in the fuel) are the essential requirements. Developing suitable structural materials is the key issue and is the governing factor for maximum achievable burn-up in fast reactor fuels. As regard to structural materials, these are being researched and evolved continuously, to meet the higher standards of performance. The current state-of-the-art material namely, D9 allows achieving a burn-up of about 100 kWd/g. Extensive R&D including post irradiation examination (PIE) techniques are required to achieve a target burn-up of 200 kWd/g. As far as coolant is concerned, the liquid metal, particularly sodium has been the preferred choice. However, there are many challenging issues in both science and technology, that are being addressed, particularly in the domains of sodium chemistry, sensors, mechanical behaviour of materials in sodium, non-destructive examination (NDE), including in-service inspection (ISI) techniques in sodium (opaqueness of sodium poses a challenge), thermal hydraulics and structural mechanics. In addition, for meeting the requirements of commercial deployment in a sustainable way, FBR and closed fuel cycle have to be designed with improved economy and enhanced safety. Towards improving safety with enhanced natural heat removal capability, pool type concept is generally adopted in which the entire primary sodium circuit is housed within a single vessel with associated thin shell structures. Manufacturing of such a thin and large dimensioned shell structure, with the possible minimum manufacturing deviations (dictated by functional requirements and seismic considerations) call for many challenging and innovative manufacturing processes. Further, there are a few challenging technological issues such as development of robust welding and hard facing techniques, design and development of large diameter bearings, elastomers, etc.

In order to pursue R&D activities to achieve the goals of mission programmes of our Centre, IGCAR houses sophisticated facilities for large component testing and evaluation of component behaviour under seismic loading. R&D programmes in the domains of materials development, structural mechanics, design, manufacturing, NDE, computer applications and instrumentation have been peer reviewed and assessed for purpose and competence. The manufacturing capability of industries has also proven to be complete to ensure indigenous fabrication of all components of sodium cooled fast spectrum reactors which can be considered as international benchmark.

The experiences gained and challenges addressed during successful operation of FBTR for 25 years and progress made by the Centre in the R&D and technology development in the last forty years has culminated in the design of 500 MWe Prototype Fast Breeder Reactor, which is fast approaching the completion of construction at Kalpakkam. Considering the significant role the FBRs are likely to play towards the energy security of the nation, commissioning of six more 500 MWe FBRs, within the next decade has become a necessity. Improved design and safety, higher breeding gain, longer plant life and effective closure of the fuel cycle are the important factors for the success of our FBR program which forms the second stage of the nuclear power program as envisioned by Dr. Homi Jehangir Bhabha. We also have plans to switch over to metallic fuels for FBRs owing to their inherent advantages. Though the goal is clear to commission the reactors with enhanced safety and improved economy, the road map has lot of challenges and necessitates substantial R&D and involvement of additional skilled manpower etc. and needs to be addressed very quickly, taking consideration the targets we have set for ourselves.

At our Centre, multitude of steps have been taken up to meet the challenges ahead for mastering the technology for large scale deployment of nuclear reactors for assuring energy security to the country. Training school is established at Kalpakkam to make available quality manpower well trained in fast reactors and associated fuel cycle technologies. Concerted effort has been made to identify the gap areas in research to be carried out on priority by various Units of the Department. At our Centre, large numbers of research scholars are pursuing their doctoral programs in the areas at the interface of science and technology, research and development. The number would grow in the coming years with appropriate infrastructure becoming available.

Vibrant academia-research institute-industry interaction is playing an important role in completing the challenging tasks towards finding solutions for the mission programmes of the Centre and the Department. Research and Development through collaborations have helped in generating critical inputs in shorter than expected time, development of several centers of excellence, incorporating up-to-date manufacturing and inspection technologies for manufacture of large and precision engineered components and for hybridization of ideas. As I have reiterated several times in the past, pursuit of collaborative approach with academic and research institutions and indigenous industries can only accelerate the pace of our R&D efforts. The Centre has established close interaction with industry for transforming the ideas from design to manufacturing of the large sized and critical components. These collaborations aided in innovating and achieving breakthroughs, deeper understanding and to realize science based technologies.

IGCAR has collaborated with more than ninety five institutions including thirteen international institutions. The collaboration has been mutual, while we bank on our expertise and infrastructure; we have utilized the capability of the institutions in providing vital inputs towards the development of Fast Reactor technology. These robust interactions have matured over the years and have started yielding results.

"If you have an apple and I have an apple and we exchange these apples then you and I will still each have one apple…
... but if you have an idea and I have an idea and we exchange these ideas, then each of us will have two ideas"

-George Bernard Shaw

Methodology

We are successful in establishing a fruitful collaboration owing to the methodology adopted by us. Our strategy has been to prepare a consolidated list of R&D challenges and identify areas wherein we would be able to identify institutes and research establishments, which have strength in those areas. After listing the statement of objectives and identifying the nature of the work to be executed, we undertake visits to the prospective institutions by giving general lectures and gradually narrowing down to the specific areas like R&D requirements and project topics. We hold detailed discussions with the prospective specialists and peers in the field of interest. Once the project proposals are submitted by institutes, they are scrutinized by multi-level reviews both internally and also at the institute. The projects are then sanctioned and executed. We hold periodic reviews and make an assessment of the progress, intervening and supporting wherever required. The projects are then taken to logical conclusion with the submission of the completion report.

- Preparation of consolidated R&D list
- Identification of areas which can be executed by Institutes & Research Establishments
- Statement of objectives
- Identifying the nature of work (theoretical/ experimental)
- Visits to prospective institutions to deliver lectures on overall programme of the Centre, plant features, R&D requirements and project topics
- Detailed discussions with the prospective specialists
- Lecture by specialists in the area of specialisation
- Submission of project proposals by the institutes
- Review by internal/institute level
- Sanctioning and execution
- Periodic reviews
- Submission of completion report
- Presentation by Investigators and Review

Key Factors for the Success

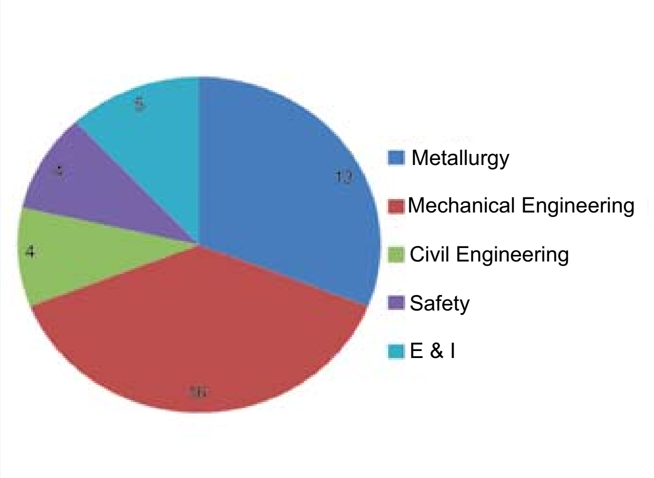
The success, symbiosis and the synergy of the collaborations are due to the dedicated and continued support from investigators, dedicated coordinators, clear definition of the project proposals, superior quality of the project proposals, appreciation for investigators/coordinators and the publications coming out of such collaborations. We are happy that these collaborations have not only led to the development of technology but also resulted in innovations and breakthroughs in technologies where research has been carried out. We are committed to involving young teams and taking the projects to logical conclusion.

- Dedicated & Continued Availability of Institute Professors (Investigators)
- Dedicated Coordinators
- Clear Definition of Project Proposals
- Quality of Project Proposals
- Periodic Reviews at Higher Level
- Institute Responsibilities
- Appreciation for Investigators and Coordinators
- Publications

In this article I would like to highlight the success of one of the oldest and sustaining collaboration our Centre has been having with Indian Institute of Technology-Madras (IIT-M), Chennai.

About collaborative projects with IIT-M

The interaction with IIT-M started in 1995 through two collaborative projects, which were initiated with late Dr. R.S. Alwar, eminent professor in Applied Mechanics. The first project was on simulation of thermal shock on the control plug mockup and the second was on simulation of thermal striping in the core structure. An MoU was established on July 19, 1997 for the formation of 'IGCAR- IITM Cell' with Prof. R. Natarajan (then Director, IIT-M) as Chairman and late Dr. Placid Rodriguez as Co-Chairman. Prof. K.V.S. Rama Rao was Dean, ICSR during that period. In the first cell meeting held on February 26, 1997, seven projects were identified. Based on the decisions taken in the meeting, four projects with a funding to the tune of eighty eight lakhs were sanctioned. In the past thirteen years, twenty five meetings of the IGCAR-IITM cell have been conducted. Already twenty nine projects have bee completed with the funds to the tune of 405 lakhs and fifteen projects are in progress with a funding of 340 lakhs. The domains for collaborative research have been expanded from mechanical, civil and applied mechanics to



Collaborative projects - Discipline wise chemical, computer science, metallurgy and electrical engineering. The duration of implementing the project varied from one to three years.

We have consolidated the list of R&D components that can be executed through collaborative effort and a document has been prepared compiling short write-ups of topics giving objectives, nature of studies (theoretical/experimental) and the required time scales for completion. Subsequently, prospective collaborators were invited to the Centre to deliver lectures on their expertise and to get an idea of the project. They have been provided with good insight about the project proposal. Subsequently, project proposals were submitted by the institutes. Based on a critical review by internal/institute level committees, the projects have been sanctioned. During the execution of the projects, they were reviewed periodically and the final report was submitted.

In the coming paragraphs I would touch upon case studies of a few significant projects that have been completed through collaborative efforts which fall into the categories of unique facilities created, sophisticated numerical predictions and safety analysis.

Unique facilities created

Studies on flow blockage effects

Consequent to partial flow blockage in a fuel subassembly, the temperature rise in the subassembly (SA) needs to be estimated accurately to confirm that the limits are respected. Such analysis is quite complex and needs thorough validation. Experimental validation with benchmark subassembly with sodium flow and simulated heat generation requires a complex test setup, which has been put up by IIT-M. The numerical technique to predict the temperature rise, under flow blockage conditions has been validated.

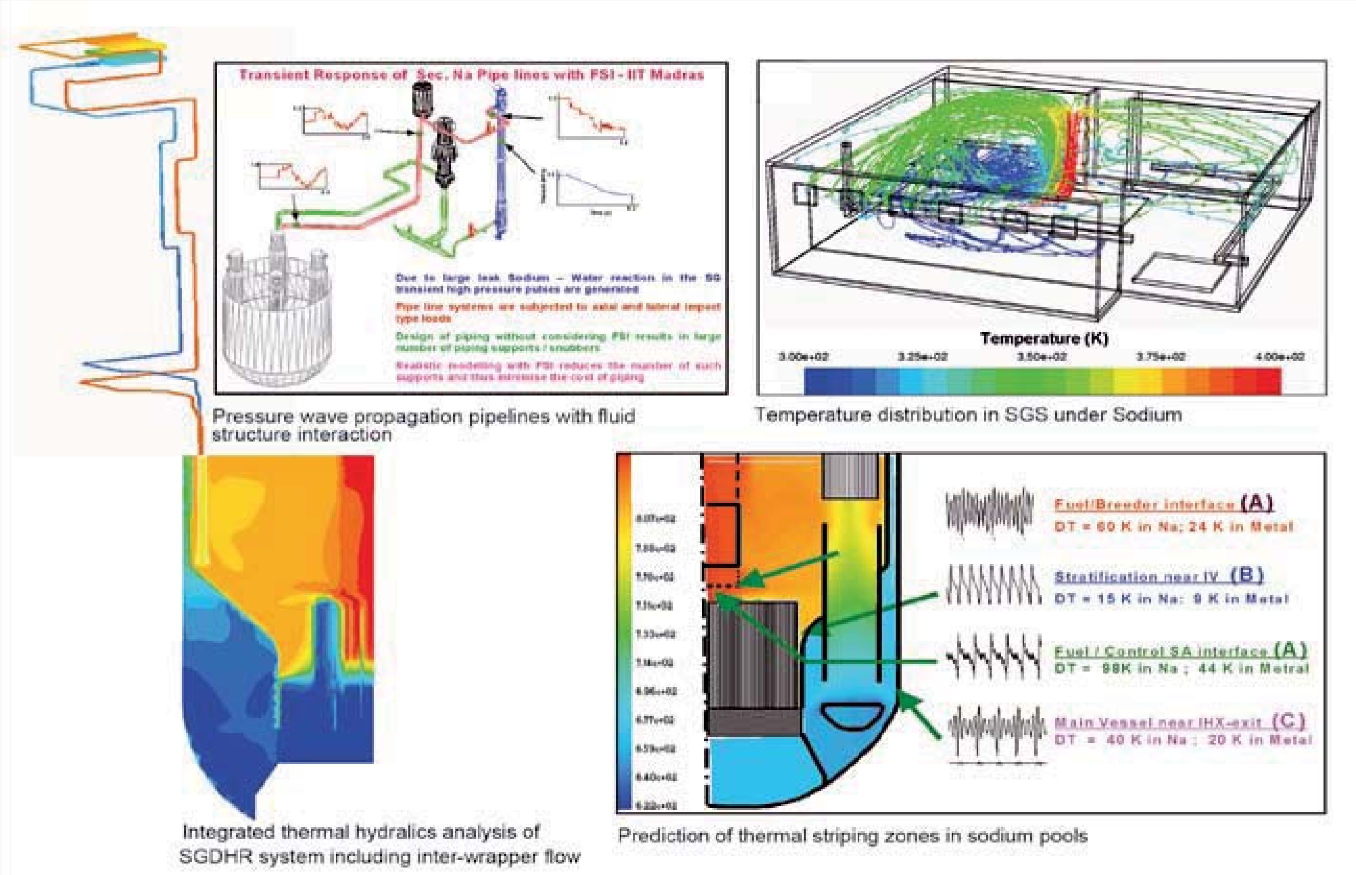
Component test facility

Since control plug is positioned above the core, it is subjected to all the transients of core and hence it is the critical component in hot sodium pool, which limits the life of the component because of accumulated creep fatigue damage. For validating the complicated viscoplastic analysis methodology, actual simulation experiments were conducted at our Centre and a component test facility was put in place at IIT-M. Hot and cold air flows are used alternatively on the component model, which is kept in the high temperature furnace to simulate thermal shock. Many shock tests have been carried out for a time period of three years and multiple thermal cracks were observed and these have been investigated at our Centre based on metallurgical and structural mechanics aspects.

Gas entrainment mechanisms

In sodium cooled fast reactors, one of the primary concern is the gas entry into the core. For incorporating any design modifications, there is a need to understand various gas entrainment mechanisms operating in the hot pool. These have been systematically studied

Some unique facilities established



Work carried out in the area of computations and numerical analysis

based on scaled down tests in water, which has given an excellent insight into this complex mechanism.

Buckling of inner vessel model

The torus portion of the inner vessel could be subjected to buckling under the internal pressure and concentrated forces through six stand pipes. The experiment has been simulated by tests on 1/8th scale down models of inner vessel, made up of stainless steel. The tests were conducted at IIT-M and results have been predicted by buckling analysis numerically with finite element codes CAST3M and ABAQUS.

Buckling of main vessel models

The cylindrical portion of main vessel is subjected to shear as well as shell mode buckling under forces and moments generated due to seismic events. In view of the fact that the prediction of buckling loads has uncertainty, which called for higher factors of safety tests and were conducted. In order to have optimum safety as well as to validate the numerical predictions, ABAQUS and CAST3M codes were employed.

Sophisticated numerical predictions

Integrated thermal hydraulics analysis of SGDHR system including inter-wrapper flow

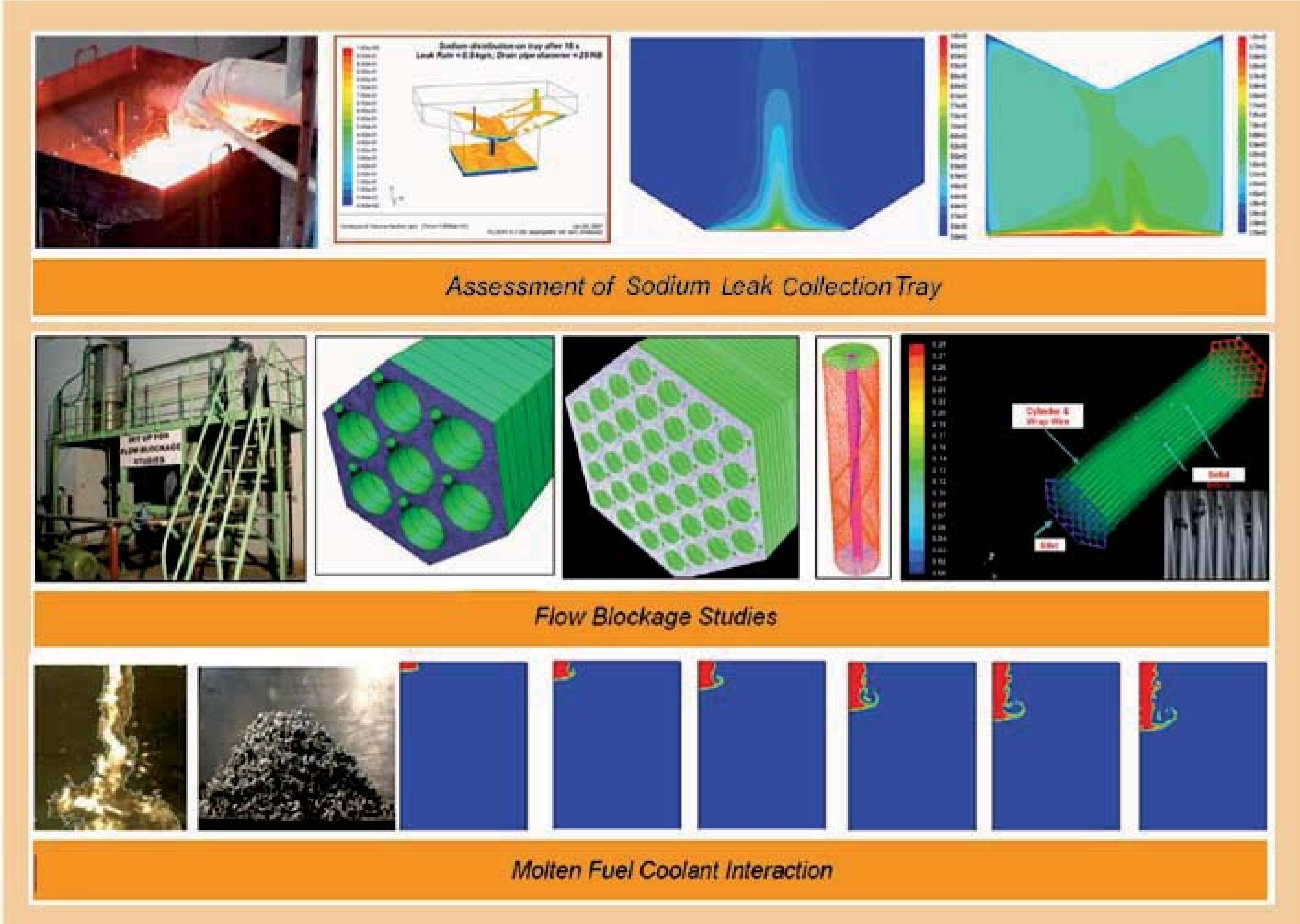
One of the uncertainties in decay heat removal system is integrated effort of pool hydraulics, i.e assurance flow through decay heat exchangers immersed in hot pool. Towards this, CFD analysis is carried out, which calls for simulation of entire circuit starting from the pool to air heat exchangers. The results from the projects aided in obtaining safety clearances for PFBR.

Effect of fluid structure interaction on the pressure wave propagation in the sodium pipe lines due to large sodium water reaction in the steam generator

From the literature, it is clear that, fluid structure interaction effects the dynamic pressures experienced at various pipe bends, leading to significant reduction, which in turn helps to reduce the number of shock arrestors called 'snubbers'. IIT-M developed a validated computer code and also carried out a sample calculation for PFBR pipeline. This code has high potential for optimization of snubbers for future FBRs.

Temperature distribution in steam generator building under sodium fire

Sodium leak is one of the postulated events for safety analysis to be considered in secondary sodium circuit in steam generator building. In the event of a sodium fire in the building, thermal energy is introduced, which subsequently results in rise in the temperature. Thermal hydraulic analysis of such a scenario forms an important input to estimate the ultimate aerosol and hydrogen release rates.



Some interesting results on safety analysis (tests at IGCAR, simulations at IIT-M)

Numerical prediction of thermal striping zones in the hot and cold pool in the reactor assembly

By using advanced CFD simulation methods, thermal striping zones have been predicted using FLUENT code, which are essential for validating the specified thermal striping values for PFBR reactor assembly components.

Safety Analysis

Sodium leak

Sodium leak is an important safety issue in Sodium Cooled Fast Reactors. Leak collection trays are generally provided to minimize the sodium fire in the building. Since only limited information is available, there is a need to arrive at the design parameters through numerical simulations. This complex analysis has now been completed effectively and important design data were generated through this project. IGCAR generated the data required for the validation through tests.

Flow blockage and simulation

Simulation of partial flow blockage scenario starting from the entry of certain shapes and sizes of objects through inlet sleeve is an involved CFD calculation. This has been done very effectively at IIT-M, probably for the first time anywhere. Animation created through this project provides excellent visualization of flow blockage scenarios. The data generated at our Centre through tests were used for the validation.

Molten fuel relocation

One of the challenging numerical simulations is to predict the molten fuel relocation through transport of sodium, resulting from a core disruptive accident. The important phenomena to be simulated are fragmentation and settlement of the solidified fuel particles on the core catcher. The first phase of CFD analysis completed at IIT-M was able to simulate relocation phenomenon quite satisfactorily.

These are a few examples of success and mature partnership we have nurtured with IIT-M in these long years of association. We are focusing on taking these collaborations to newer levels by initiating mega collaborations with academic institutes like IIT-M. We believe that such efforts would result in providing us the required inputs to validate newer concepts to be incorporated in the design of fast reactors and associated fuel cycle technologies with enhanced safety and in a more economical way.

(Baldev Raj)
Director, IGCAR

Advanced Visualisation Centre

The Centre is involved in the design and analysis of complex plants like fast breeder reactors, fuel cycle facilities, etc. In order to facilitate the design, construction and maintenance of such complex plants it has been envisaged to set up a state-of-the-art fully immersive advanced visualization centre at Computer Division.

The visualisation centre will aid in viewing the 3D models developed using 3D modelling software to view in real 3D with depth perception compared to viewing in normal 2D displays on the desktop. To make the environment fully interactive and immersive, virtual hand with force feedback systems are used. There are different ways of visualisation of 3D models.

TYPES OF STEREOSCOPIC DISPLAYS

Basically, there are two display methods available to view the models in 3D namely active and passive display systems.

ACTIVE STEREO

The "active stereo" refers to the use of glasses with liquid-crystal shutter lenses. In conjunction with compatible software, these glasses ensure that the frames specified for the left and right eye respectively are correctly displayed. With each eye seeing a different perspective, objects create an illusion of depth and physical presence. The frame rate required for stereoscopic viewing is gauged as a refresh frequency per second. This frequency must be above 96 Hz, or rather 48 fps (frames per second) per eye to achieve flicker-free viewing. Because of continuous switching of left and right eye shutters, the solution will strain the viewers after continuous viewing for more than fifteen minutes.

PASSIVE STEREO

"Passive stereo" is a different display method using two projectors. These are placed side by side, providing two slightly different projections of the 3D software model. The light from one projector is polarised to 45 degrees, and the light from the other projector is polarised to 135 degrees. By using special glasses that let through 45 degrees of polarised light to get through on one glass and 135 degrees of polarised light on the other, a stereoscopic image is achieved. This will give the audience strain free viewing for hours together.

DESCRIPTION OF THE ADVANCED VISUALISATION SYSTEM

The advanced visualisation system consists of high definition projectors with high luminance, circularly polarized filters, circularly polarised viewing glasses, high gain silver coated screen, special purpose powerful graphics workstation with dual graphics cards supporting stereoscopic viewing with 3GB of video memory, advanced 3D modeling software having features to model mechanical assembly, piping design, heating, ventilation, air condition design, structural design and tubing design. The animation software provides digital assembly process simulation, human task simulation including Rapid Upper Limb Assessment (RULA) analysis and creation of forward / inverse kinematics of devices. The visualisation software provides visualisation capabilities like setting illumination levels, setting camera positions, adding materials, textures, grids and paths in stereoscopic 3D environment, assigning physical properties to the models to make it as closely as possible to the real world. Using artificial intelligence library can develop autonomous characters capable of evaluating their environment with visual and aural sensory abilities and then manage characters' subsequent actions with high-level behaviours .

In addition, the set up also consists of digital 2.1 sound system, variable luminance lighting system, wireless touch panel control system, hand glove with force feedback system and acoustically treated floor, wall, ceiling panels, etc.

The system has been setup with a seating capacity of twenty persons (Figure 1) for a perspective view of the advanced visualisation centre. The display technology used is passive circular polarised stereo projection. Two high definition projectors of resolution 1920 x 1080 pixels and 6500 luminance each have been installed. One projector will project the left eye image and the other projector will project the right eye image. The projectors will project the images overlapping both the images on the special silver coated screen of size 16 feet width x 9 feet height. The graphics workstation with the help of visualisation software will generate a separate image for each eye. There are two graphics cards installed in the workstation. The digital output of each card is connected to the respective projectors. By wearing the passive polarised glasses one can experience the viewing of real 3D display.

Variable luminance lighting system helps to adjust the lighting of the room for viewing the models. The audio system provides excellent and clear sound effects to add audio to the models like description of the system or add simulated sounds of equipments demonstrated in the model. The lighting system, audio system, video system can be controlled from the wireless touch panel control system. Lights can be switched on/off or luminance can be adjusted from the touch panel. The volume of speakers can be adjusted or it can be muted from the touch panel. The video system operation is provided with the option of 3D projection or normal projection. Also the entire system can be shutdown from the touch panel control system after completion of visualisation. The touch panel control system provides complete and smooth operation of the system. The entire room is acoustically treated for complete immersion. The audience seating has been provided with ergonomic chairs for comfortable viewing and stepped flooring for clear unobstructive viewing of the screen.

For interactive and immersive applications virtual hand consisting

Figure1: Perspective view of advanced visualisation centre

Figure 2: Visualisation of 3D model of PFBR control plug

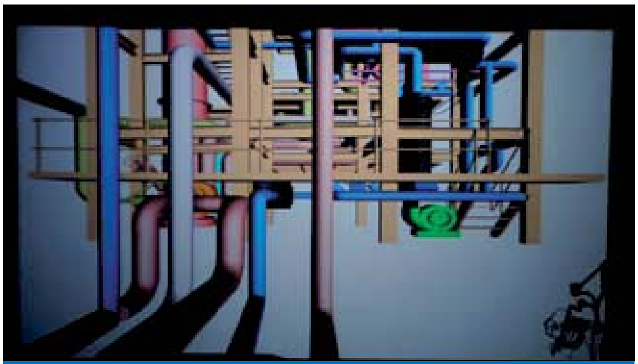


Figure 3: Visualization of walkthrough of steam generator test facility

of hand glove and force feedback system has been configured and installed. Using this system a person can touch, grasp and get the feel of physically defined objects inside a plant, which will be useful for commissioning and maintenance of the plant.

APPLICATIONS

Complete walkthrough of a plant including many human-centered activities can be simulated in full one-to-one scale, such as navigation, orientation, and object identification and manipulation. This will help the designers in finalising the plant layout in a better way. For PFBR, a walkthrough on the entire nuclear island building and conventional system buildings is being developed. A typical walkthrough will show a person entering a building and will enable viewing all the important components of that building elevation wise. This can be used to train the operation and maintenance personnel which will serve as a bridge between theory and operations.

Scientific data like geological modeling, finite element analysis data from simulation or experiments can be viewed to allow the exploration, analysis and understanding of the data. For example uranium mining exploration data can be ported to the system and visualised for better understanding. Various thermal hydraulics and structural mechanics analysis of FBR can be viewed in 3D for easy interpretation of the analysis. Also visualisation of in service inspection of reactor internals can be studied for reviewing the design.

A digital mock up of design review could be performed looking for any errors and inconsistencies. For example, clash detection in congested areas like top of roof slab at an elevation of thirty meters of reactor containment building, thermocouple tube routing of control plug can be identified. We can study whether sufficient space is there in the control room of the reactor for effective utilization of area can be done. Clash studies of inter disciplinary systems like cable trays with piping or other systems like air conditioning ducting, steel structures etc can be identified .

Construction activity review can be done by turning on/off the respective models and see the progress of construction of a plant. A mock up of the sequences of the various construction activities can be tried prior to the actual construction. This reduces the construction period and enables smooth construction activity.

The visualisation centre helps in performing the mock equipment installation. The various sequences of equipment installation can be tried out to find out and finalise the optimal installation and commissioning method of the various equipments.

The Advanced Visualisation Centre can be used as a mock up maintenance training tool. As the plant walkthrough helps the maintenance engineer in the first phase in understanding the layout of the equipment, it also helps in rehearsing the procedures in removing parts / maintaining any system. For example, removing a motor in the space available or removal of steam generator for repair work can be studied virtually.

The engineers and the operators who have joined the group after the construction of the plant will never get an opportunity to see all the subsystems in the plant. In addition to providing theoretical training, the engineers / operators could be trained in the complete walkthrough of the virtual 1:1 scale model of the plant for better understanding of the plant.

The various components of PFBR reactor assembly has been ported to the visualization centre (Figure 2) visualization of 3D model of PFBR control plug and (Figure 3) Visualization of walkthrough of Steam Generator Test Facility (SGTF) for viewing in 3D environment to attain the benefits listed above. Recently using this setup the complete control room consisting of control and console panels of PFBR has been modeled and a walkthrough of control room has been developed. Currently modeling of a very challenging fuel handling system of PFBR is being done. All the subsystems of fuel handling system are being 3D modeled and animation of the sub system is being done. Then integrated animation of the fuel handling is being ported to the visualisation centre for viewing in 3D and for interactive animation.

IN SUMMARY

The advanced visualisation centre has been designed and installed to help the designers to view the 3D models in fully immersive interactive 3D environment. It will help in design of future FBRs for finalising the plant layout , for clash detection analysis, view the entire plant and do a digital mockup construction sequence of the plant before actual construction starts , for virtual equipment installation and maintenance operation. These factors will reduce the design and construction time of the plant and in turn help in reducing the overall cost of the project.

(Reported by J.Rajan and colleagues, Computer Division)

Assessment of Baseline Cytogenetic Damage in Fishes Inhabiting the Backwaters of Kalpakkam

Backwaters in India are unique water-bodies enriched with a wide variety of species biodiversity. As ecosystems, backwaters are under threat from pollutants from various sources such as industrial activities, agricultural and urban land runoffs. These contaminants accumulate in the species inhabiting these water-bodies and may enter the human food chain. Moreover, aquatic organisms like fishes are used as "sentinel species" to determine the effects of toxic pollutants.

Backwaters also serve as fishing grounds and those at Kalpakkam offer a livelihood to the local community. A study was undertaken to assess the baseline DNA damage in apparently healthy fishes caught from the backwaters within the Kalpakkam Township. As no data is available on the species biodiversity of this ecosystem, as a first step, an effort was made to establish the piscine biodiversity. Fishes were caught at various locations in the Kalpakkam backwaters within township during summer months and were identified. The specimens that were collected from the respective sampling sites were preserved in 10% formalin in plastic containers and carried to the Zoological Survey of India (ZSI), Chennai for identification. Among these, commonly available edible fishes such as Tilapia, Catfish, Jarbua and Pearlspot were used for the assessment of DNA damage.

THE CYTOME ASSAY

The cytome (micronucleus) assay is a simple and sensitive test for in vivo evaluation of genotoxic properties of various agents. Micronuclei are small, extra nuclear bodies that are formed during mitosis from acentric chromosomal fragments caused by the action of genotoxic agents such as pesticides, heavy metals and radiation or chromosomes that are not included in either daughter nucleus. After telophase these fragments may not be included in the nuclei of daughter cells and form single or multiple micronuclei in the cytoplasm.

METHODOLOGY

About 0.1ml of blood was drawn from the caudal vein of the fish using a heparinised syringe and thin smears were made on pre-cleaned microscope slides. The slides were air-dried, fixed in absolute methanol and stained in May-Grunnwald's followed by Giemsa solutions. Peripheral blood erythrocytes were scored under 1000 X magnification using a light microscope (Nikon, Germany) and recoded on data sheets.

OBSERVATIONS

DNA damage in the form of various types of cytogenetic aberrations such as micronuclei (fragments of chromosomes that appear as circular dots smaller than the main nuclei), deformed nuclei (nuclei with vacuoles or voids with appreciable depth into the nucleus), binucleated cells (cells with two nuclei in a single cytoplasm), nuclear buds (nuclei with a relatively small evagination of the nuclear membrane containing euchromatin), apoptotic cells (nuclear fragmentation in the cytoplasm), anisochromasia (unequal distribution of hemoglobin in the erythrocyte), multiple micronuclei (more than one micronuclei in a single cell), vacuolated cytoplasm (a prominent vacuole in the cytoplasm), enucleus (cytoplasm without nucleus) and altered cell morphology (change in the normal elliptical shape of the cell) were observed in these apparently healthy fishes (Figure 1).

In order to compare the aberration frequency, fishes of the same species like Tilapia reared in controlled conditions and clean waters in fish farms were subjected to the cytome assay.

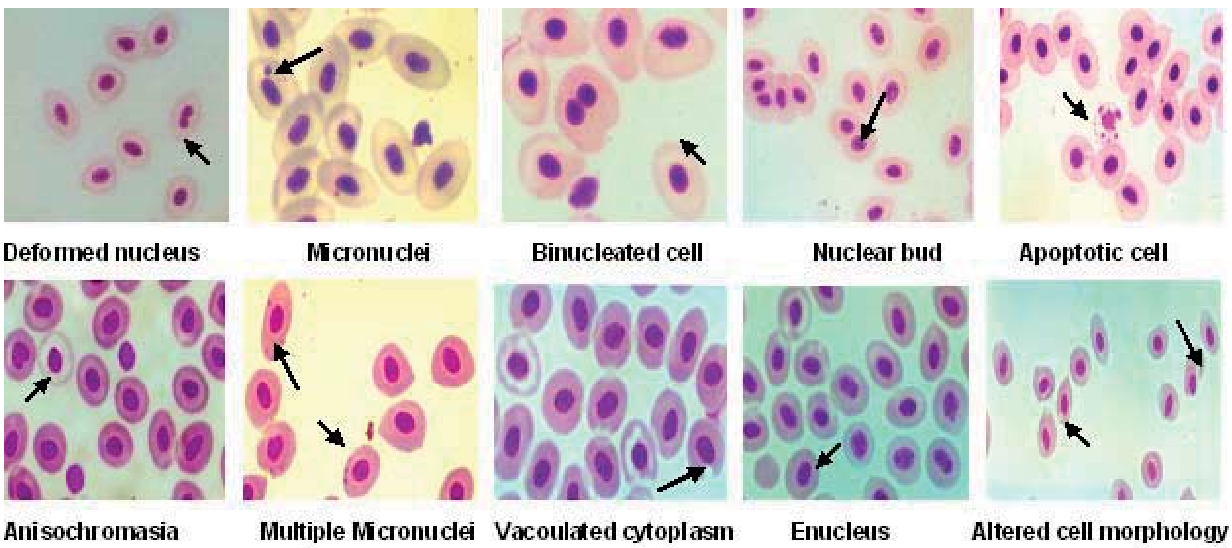


Figure 1: Various types of aberrations observed in blood erythrocytes from the fishes of Kalpakkam backwaters

Table 1: Levels of Organochlorine residues (ppm wet weight) in fish tissues

S.No	Name of the Pesticide	TG1	MG1	TM1	TM2	TM3	TM4	MM1	MM2
1	α HCH	0.0005	0.0004	0.0001	0.0002	BDL	BDL	0.0012	0.0003
2	β HCH	0.0007	BDL	0.0026	BDL	BDL	BDL	0.0017	BDL
3	γ HCH	BDL	0.0084	0.0826	0.0057	0.0023	0.0031	0.0214	0.0005
4	δ HCH	BDL	BDL	0.0122	BDL	0.0005	BDL	0.0119	BDL
5	Heptachlor	0.0023	BDL	0.0130	BDL	BDL	BDL	0.0070	0.0018
6	Heptachlor epoxide	0.0175	0.0011	0.0430	0.0005	0.0005	0.0007	0.0110	0.0005
7	Dieldrin	0.0021	0.0023	0.0803	0.0009	0.0015	0.0004	0.0085	BDL
8	Endosulfan A	0.0050	0.0037	0.0244	0.0023	0.0011	0.0020	0.0072	0.0009
9	Endosulfan B	0.0019	0.0014	0.0144	0.0006	0.0007	0.0005	0.0038	BDL
10	Endosulfan sulfate	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
11	p, p' – DDT	BDL	0.0023	BDL	0.0012	0.0017	0.0016	BDL	0.0070
12	p, p' – DDE	0.0008	BDL	0.0311	BDL	BDL	BDL	0.0098	0.0028
13	p, p' – DDD	0.0015	BDL	0.0071	BDL	BDL	BDL	0.0055	BDL

TG – Tilapia gill **TM** – Tilapia muscle **MG** – Mugil gill **MM** –Mugil muscle

Aberrations such as micronuclei and their frequencies observed in the fishes inhabiting the backwaters were found to be about a hundred times higher than those observed in fishes reared in fish farms.

ESTIMATION OF PESTICIDE RESIDUES AND HEAVY METALS

The Environmental Survey Laboratory at Kalpakkam routinely monitors the radionuclide levels in aquatic organisms and has always reported cesium and strontium levels at below detectable limits. In order to identify the likely causative agent of Deoxyribo Nucleic Acid damage in these apparently healthy fishes, chemical analysis of pesticide residues and heavy metals in tissue samples were performed. Pesticides such as 2,4-dichlorophenoxyacetic acid, DDT and its products, diazinon, endosulfan, lindane and other breakdown products like bisphenol A, dioxins, nonylphenol, polychlorinated biphenyls and some phthalates are known to be potent endocrine disrupting chemicals (EDCs) in fishes. The long-term effects observed are egg-producing cells in male testis, reduced testis growth rate and size, female reproductive tracts in males, increased liver size and increased levels of vitellogenin (egg protein) (www.ngo.grida.no/wwfneap/Publication/briefings/Fish.pdf).

Table 2: Levels of heavy metal concentration (ppm wet weight) in fish tissues

	Sample			
Metal	**1**	**2**	**3**	**4**
Cadmium	0.003	0.005	0.004	0.004
Chromium	0.122	0.108	0.089	0.037
Zinc	0.339	0.211	0.640	0.270
Copper	BDL	BDL	BDL	BDL
Lead	BDL	BDL	BDL	BDL

Tissue samples were carefully dissected from Tilapia and Mugil species and transported to Salim Ali Centre for Ornithology and Natural History (SACON), Coimbatore, for analysis of organochlorine pesticides (Heptachlor, lindane, endosulfan, Dichlorodiphenyltrichloroethane, Benzene Hexa Chloride, Hexa Chlorocyclo Hexane, aldrin, dieldrin and endrin) and heavy metals (cadmium, chromium and zinc) residues (Table 1 & 2).

The concentrations of pesticides and heavy metals were observed to be below the prescribed permissible levels of the Food and Agriculture Organisation and World Health Organisation. Presently available methods for setting up the permissible limits in fishes for human consumption are mostly based on exposures to acute doses that produce adverse effects. However, chronic exposures are of equal concern as these may trigger endocrinal changes and lead to sex reversals and malignancy in the long run. Sensitive assays based on assessment of DNA damage after chronic exposures are therefore required to monitor and recommend permissible limits to control environmental pollution. The significant DNA damage observed in the present study in apparently healthy fishes shows that the erythrocyte cytome assay is a sensitive technique to detect DNA damage due to chronic low dose exposures to chemicals and other environmental mutagens and hence serve as a more sensitive assay of risk assessment in the field of aquatic toxicology.

(Reported by S. Anbumani and colleagues, Radiological Safety Division)

Young Officer's FORUM

Formulation of a New Material Model for Prediction of Flow Behaviour in Alloy D9

Ms. Dipti Samantaray obtained her Bachelor of Engineering degree in Mechanical Engineering from University College of Engineering, Burla, Orissa in 2005. She is from 1st batch of IGCAR training school. She joined Materials Technology Division, MMG, IGCAR in September 2007.

Materials models or constitutive equations are mathematical representation of relationships between stress, strain, temperature and strain rate. These equations are used to predict flow stress of material when other processing parameters are known. The relationship between stress, strain, temperature and strain rate vary from material to material and also for different materials working domains. A single equation may not be sufficient to describe the flow behaviour of all available materials in a specified domain or of a specific material in all material working domains. Ideally, a constitutive equation should involve reasonable number of material constants, which can be evaluated using limited number of experiments, and should be able to represent the flow behaviour of the material with adequate accuracy and reliability over a wide material processing domain. Among the available empirical models, the Johnson-Cook (JC) model is considered as a benchmark as it contains only five material constants and requires only five experiments to evaluate those constants. Additionally the JC model considers the effect of three most significant parameters, viz. strain, temperature and strain rate, on the flow stress. However, the JC model does not consider the coupled effects of temperature and strain or of temperature and strain rate on flow stress. The model that considers the coupled effect of temperature and strain rate along with the effects of strain hardening and temperature softening on the flow stress in fcc materials is the Zerilli-Armstrong (ZA) model. Although the ZA model contains five material constants, it has not been used to predict flow behaviour of materials in hot working domains. In view of the above, a new materials model has been formulated to predict the flow behaviour of Alloy D9 over a wide range of temperature (1073–1473 K), strain (0.1–0.5) and strain rate (0.001–1 s^{-1}), by suitably modifying the ZA model.

In the original ZA model, the flow stress for fcc materials is expressed as:

$$\sigma = A_0 + A_1\varepsilon^n \exp(-A_2T + A_3T\ln\dot{\varepsilon}) \quad (1)$$

where σ is the (Von Mises) flow stress, ε the equivalent plastic strain, $\dot{\varepsilon}$ the strain rate, T the absolute temperature, A_0 the athermal component of yield stress, and A_1, A_2, A_3 and n are the material parameters. Our modified version of the ZA model is represented as:

$$\sigma = (C_1 + C_2\varepsilon^n)\exp\{-(C_3 + C_4\varepsilon)T^* + (C_5 + C_6T^*)\ln\dot{\varepsilon}^*\} \quad (2)$$

where $T^* = (T-T_{ref})$ with T and T_{ref} being current and reference temperatures, respectively, $\dot{\varepsilon}^*$ is the dimensionless strain rate expressed as $\dot{\varepsilon}^* = \dot{\varepsilon}/\dot{\varepsilon}_0$ with $\dot{\varepsilon}$ and $\dot{\varepsilon}_0$ being current strain rate and reference strain rate, respectively, and $C_1, C_2, C_3, C_4, C_5, C_6$ and n are material constants. The basis for modification of the ZA model to make it suitable for prediction of elevated temperature flow behaviour of alloy D9 as described below.

The ZA model, [Equation (1)], divides the flow stress into two components; thermal and athermal. The athermal component is given by A_0 and depends on grain size of the deforming material, while the thermal component is given by $A_1\varepsilon^n \exp(-A_2T + A_3T\ln\dot{\varepsilon})$. However, Figure 1 shows that above 873 K the yield stress of alloy D9 decreases with increase in temperature. Hence, the athermal component of flow stress has been neglected in the modified equation, [Equation (2)].

According to the ZA model, the $A_1\varepsilon^n$ term of Equation (1) is calculated from the intercept of *ln* $(\sigma - A_0)$ *versus* T plot at $\dot{\varepsilon} = 1 s^{-1}$. This implies that the intercept of the *ln* $(\sigma - A_0)$ *versus* T plot represents the flow stress at 0 K. These intercepts for various strains are plotted against *ln* ε to obtain the value of A_1 and n. However, the fitting of the curve $A_1\varepsilon^n$ cannot be validated as flow stress data at 0 K is not available. For extrapolation of flow stress to 0 K, the model has been critically reviewed several times. To avoid this problem, T^* has been used in Equation(2) in place of T. At reference temperature T_{ref}, T^* becomes 0 K, where data are available for the validation of the constants. In addition to this, the difference between the temperature of interest and the reference temperature, i.e. $(T - T_{ref})$ can also incorporate the effect of flow softening, with T_{ref} being the minimum temperature of the test matrix.

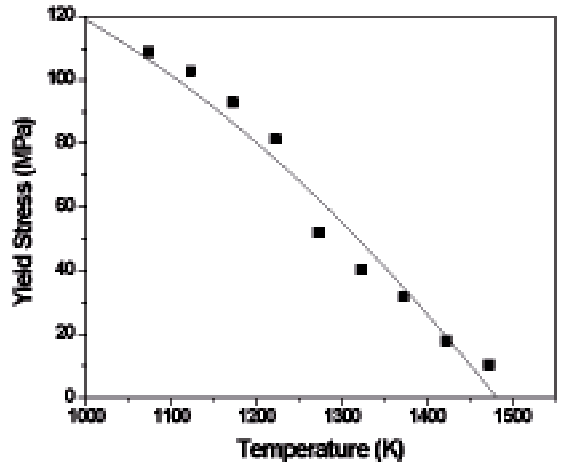


Figure 1: Variation of yield stress of alloy D9 with temperature

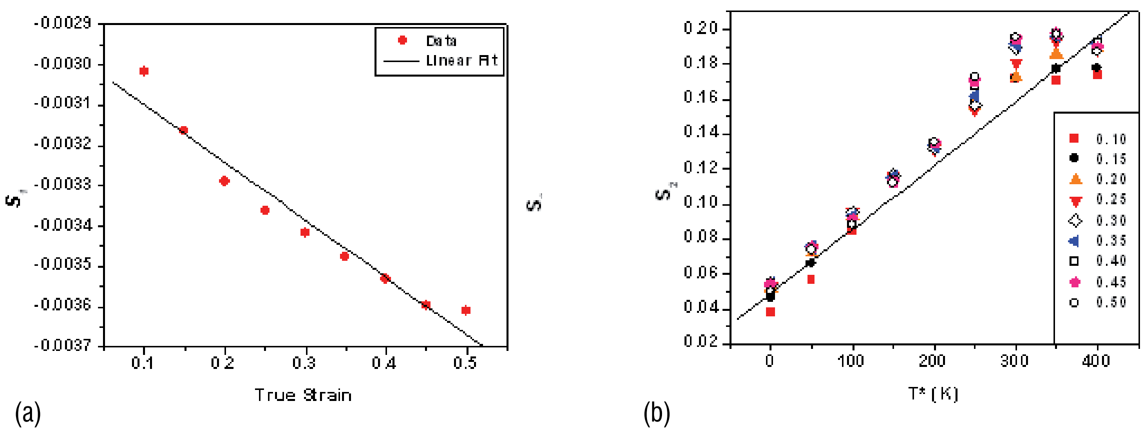


Figure 2: (a) Relationship of S_1 with true strain; (b) Relationship of S_2 with temperature at different true strain

Comparing the Equation (1) with Equation (2), it is observed that $A_1\varepsilon^n$ component of ZA model is represented as $(C_1 + C_2\varepsilon^n)$ in our modified model, with C_1 being the proof stress at reference temperature and reference strain rate, and C_2 and n being the effect of work hardening constants. Addition of a new constant C_1 is necessary for incorporating the information regarding proof stress.

The presence of $\dot{\varepsilon}$ term in Equation (1) requires a mandatory test at 1 s^{-1} for evaluation of constants. However, the replacement of strain rate $\dot{\varepsilon}$ with a dimensionless strain rate $\dot{\varepsilon}^*$ in Equation (2) does not require the test at 1s^{-1} as the reference strain rate can be defined to make $\dot{\varepsilon}^* = 1$. According to ZA model, Equation(1), in the absence of strain rate effect at $\dot{\varepsilon}^* = 1$, A_2 is calculated from the slope of *ln* σ *versus* T plot, with this slope being independent of ε. Following a similar approach, *ln* σ *versus* T^* is initially plotted and the slope S_1 is calculated at various strains. Interestingly, for alloy D9, S_1 shows a linear relationship with ε (Figure 2a). In view of the above, A_2 of Equation (1) is changed to $(C_3 + C_4\varepsilon)$ in Equation (2), where C_3 is the constant that incorporates the effect of temperature on flow stress even at very small deformation, e.g. $\varepsilon = 0.002$, while C_4 is the constant that defines the coupled effect of temperature and strain on flow stress. Again, according to the ZA model, the value A_3T is determined from the slope of the *ln* σ *versus* *ln* $\dot{\varepsilon}^*$ plot, with the constant A_3 being calculated from this slope. It is to be noted that the intercept of the A_3T versus T plot is zero. Since, this intercept indicates the effect of strain rate on flow stress at 0 K, Equation (1) does not include the absolute effect of strain rate on flow stress. Thus, the ZA equation [Equation (1)] predicts same flow stress for all the strain rates at 0 K. For alloy D9, first the slope (S_2) of the *ln* σ versus $\dot{\varepsilon}^*$ *ln* plot is calculated, with S_2 showing linear dependency with T^* (Figure 2 (b)). This intercept, which is not zero, defines the absolute effect of strain rate on flow stress at reference temperature (i.e. $T^* = 0$). Figure 2(b) further signifies that the slope does not show any significant dependency on the strain. Considering this, the slope of the *ln* σ versus *ln* $\dot{\varepsilon}^*$ plot of the ZA model is represented by $(C_5 + C_6T^*)$ in the modified equation, with the constant C_5 defining the effect of strain rate on flow stress at reference temperature and the constant C_6 representing the coupled effect of temperature and strain rate on flow stress. Thus, our proposed modified equation considers isotropic hardening, temperature softening, strain rate hardening, and the coupled effects of temperature and strain and of strain rate and temperature on the flow stress.

EVALUATION OF MATERIAL CONSTANTS

At $\dot{\varepsilon}^* = 1$, Equation(2) reduces to,

$$\sigma = (C_1 + C_2\varepsilon^n)\exp(-(C_3 + C_4\varepsilon)T^*) \qquad (3)$$

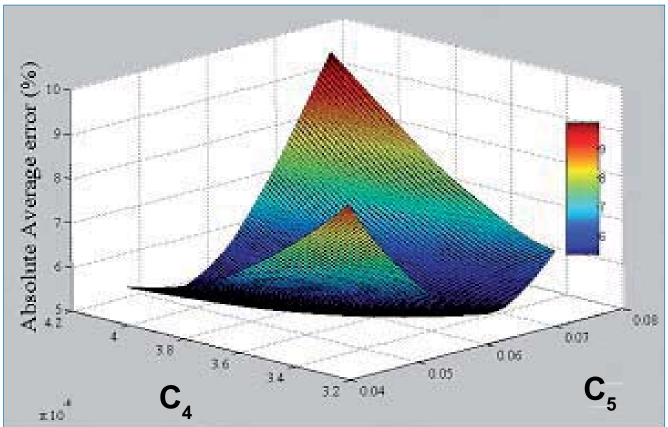


Figure 3: Variation in absolute average error for different sets of C_5 and C_6

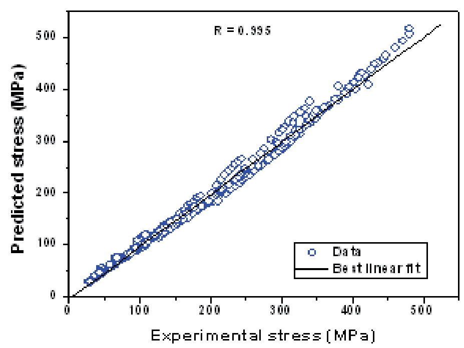


Figure 4: Correlation between the predicted flow stress and experimental flow stress constitutive equation and experimental flow stress over the entire domainof S_2 with temperature at different true strain

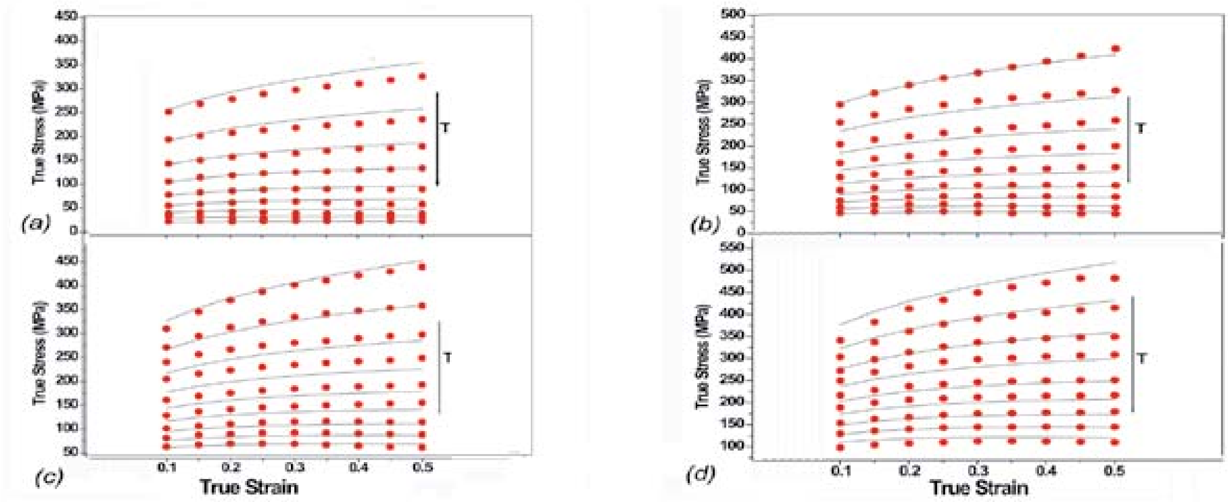


Figure 5: Comparison between the experimental and predicted flow stress at (a) $0.001 s^{-1}$ (b) $0.01 s^{-1}$ (c) $0.1 s^{-1}$ (d) $1 s^{-1}$ in the temperature domain 1073 - 1473K (in steps of 50 K) (points denote experimental values and lines denote predicted values)

Taking natural logarithm, Equation (3) can be expressed as,

$$\ln\sigma = \ln(C_1 + C_2\varepsilon^n) - (C_3 + C_4\varepsilon)T^* \quad (4)$$

Using the flow stress data at $\dot{\varepsilon}^* = 1$, the plot between *ln σ versus T** gives the value of $ln(C_1+C_2\,\varepsilon^n)$ as intercept I_1 and value of $-(C_3+C_4\varepsilon)$ as slope S_1.

Hence, by taking, $I_1 = \ln(C_1 + C_2\varepsilon^n)$ (5)

Rearranging the above equation, we have,

$$\ln(\exp(I_1) - C_1) = \ln C_2 + n\ln\varepsilon \quad (6)$$

C_1 is determined from the yield stress of the stress-strain cure at T=1073 K and $\dot{\varepsilon}^* = 1$. Substituting the value of C_1 in Equation (6) and plotting the graphs $\ln(\exp(I_1) - C_1)$ *versus ln* ε, the value of C_2 and *n* is calculated. Similarly, the slope of the line represented by Equation (4) can be written as,

$$S_1 = -(C_3 + C_4\varepsilon) \quad (7)$$

Hence, the value of C_3 and C_4, can be obtained from the Figure 2(a) as the intercept and slope respectively.

Taking natural logarithm, Equation (2) can be represented as,

$$\ln\sigma = \ln(C_1 + C_2\varepsilon^n) - (C_3 + C_4\varepsilon)T^* + (C_5 + C_6T^*)\ln\dot{\varepsilon}^* \quad (8)$$

The plot between *ln σ* and ln $\dot{\varepsilon}^*$ gives the value of S_2 as slope. For nine different temperatures, nine different values of S_2 are obtained at a particular strain. Now, the slope can be presented as,

$$S_2 = C_5 + C_6T^* \quad (9)$$

The plot S_2 versus *T** is shown in Figure 2(b). From this plot, the value of C_5 *and* C_6 is obtained from the intercept and the slope, respectively. Nine sets of C_5 *and* C_6 are obtained at different strains. These values of C_5 *and* C_6 are optimized to minimize the error between predicted and experimental data using a constrained optimization procedure to minimize absolute average error over the entire domain. The variation of absolute average error with different set of values for parameter C_5 *and* C_6 is shown in Figure 3. From the Figure, it is observed that absolute average error is minimum at 5.3%, when the value of C_5 *is 0.0524±0.0002* and the value of C_6 *is 0.000345±0.000005.*

VERIFICATION OF THE FORMULATED MATERIAL MODEL

The material constants for the proposed modified model are C_1 *=120 MPa,* C_2*=478.8 MPa, n=0.2732,* C_3*=0.00296 and* C_4*=0.00142.* The correlation between experimental data and predicted flow stress data obtained from the proposed equations is shown in Figure 4. A good correlation between experimental and predicted data is obtained.

The predictability of the proposed constitutive equation is further assessed by comparing the experimental and predicted data which is shown in Figure 5. From the Figure, it could be observed that the material model is also able to predict the trend of the experimental flow behaviour of Alloy D9 with sufficient accuracy.

CONCLUSION

A new constitutive model has been formulated based on the ZA model which considers the effect of isotropic hardening, strain rate hardening, thermal softening and the coupled effects of temperature and strain and of strain rate and temperature on flow stress. The proposed modified-ZA model predicts the elevated temperature flow behaviour of alloy D9 over wide range of temperatures (1073–1473 K), strains (0.1–0.5) and strain rates (0.001–1 s^{-1}) with good correlation and generalization. The correlation coefficient is 0.995 while the absolute average error for the entire range is 5.3%. Hence, this proposed model could be used to predict flow behaviour of alloy D9 in the specified hot working domain of strains, strain rates and temperatures with high accuracy and reliability.

(Reported by Dipti Samantaray, Materials Technology Division)

Young Researcher's FORUM

Role of Surfactant Monolayer on Phase Transitions in Spinel Ferrite Nanoparticles during Vacuum Annealing

Shri S. Ayyappan did his B.Sc., and M. Sc., Physics from Presidency College, Chennai and M.Phil., Physics from Department of Nuclear Physics, University of Madras, Chennai. He joined IGCAR as a research scholar in May 2005 and is pursuing Ph.D. on Spinel ferrite Nanoparticles under the guidance of Dr. John Philip, NDED.

Tuning the physical and chemical properties of a material at nanoscale dimensions have been a topic of intense research for the past few decades. Nanoscale materials are broadly classified into three dimensions (e.g. nanoparticles), two dimensions (e.g. nanosheets and thin films), one dimension (nanowires and nanotubes) and zero dimension (quantum dots) based on the constraints imposed on the mean free path of electrons in a material. Owing to the superior properties like quantum size effect, large surface to volume ratio and specific surface-area, these materials open new avenues to probe fundamental issues in nanoscales and a plethora of technological applications towards the development of miniature devices.

Naturally abundant magnetic iron oxide exists in a variety of phases with different stoichiometries, structures and magnetic properties. Well known and technologically important polymorphs of iron oxide are hematite (α-Fe_2O_3), maghemite (γ-Fe_2O_3), magnetite (Fe_3O_4) and wustite (FeO). Among these polymorphs, Fe_3O_4 is ferrimagnetic below 860K (Curie temperature) and crystallize to cubic inverse spinel structure with a general formula of $(Fe^{3+})[Fe^{2+}Fe^{3+}]O_4$. The round and square brackets denote the A- and B- interstitial site having tetrahedral and octahedral symmetry with four and six oxygen coordination respectively. Fe_3O_4 nanoparticles cover broad range of potential applications like high density storage devices, ferrofluids, microwave absorption, sensors, photo detectors, etc. Particularly, ferrofluid is widely used in sealing, oscillation damping, actuators, microchip valves, MRI contrast agents, cancer therapy, nanomedicine, drug delivery etc. Recent studies focus on (1) tuning the size and morphology (e.g., spherical rods, disks, cubes, star, octahedron, truncated cube, hollow sphere, rhombohedral, and more complex shapes) of ferrite nanoparticle using advanced synthesis techniques (2) Size and shape dependent optical, electrical, thermal and magnetic properties. Particularly, thermal stability and knowledge about phase transition during annealing are essential task for the better utility of these ferrite nanoparticles for high temperature applications. Many researchers paid much attention in structural transformation among the polymorphs of iron oxides under various annealing conditions. Factors influencing the phase transition of ferrite nanoparticles are preparation method, size, metal ion doping, reaction media, heating rate, etc. Apart from these parameters, surfactant can also play an important role in phase transition of ferrofluid during annealing which has not been well explored in literature. Surfactant molecules are often used to control the particle size, produce stable ferrofluids and prevent the surface of the nanoparticles from reactive atmospheres. The present article is focused on the role of surfactant monolayer on the phase transitions of spinel ferrite Fe_3O_4 nanoparticles during vacuum annealing.

Oleic acid coated and uncoated spinel ferrite Fe_3O_4 nanoparticles are synthesized using simple co-precipitation technique, where metal ions of Fe^{2+} and Fe^{3+} ions are precipitated with an alkali. Finely smashed powder is placed uniformly on tantalum heating stage equipped with high vacuum chamber. Temperature is raised

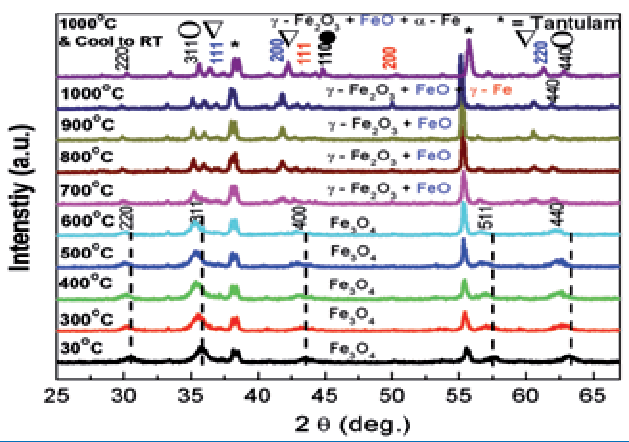


Figure 1: In situ XRD patterns of uncoated Fe_3O_4 nanoparticles at different annealing temperature in vacuum and cooled it back to room temperature. Dashed line: Fe_3O_4, open circle: γ-Fe_2O_3, open triangular: FeO, and solid circle: α–Fe phase

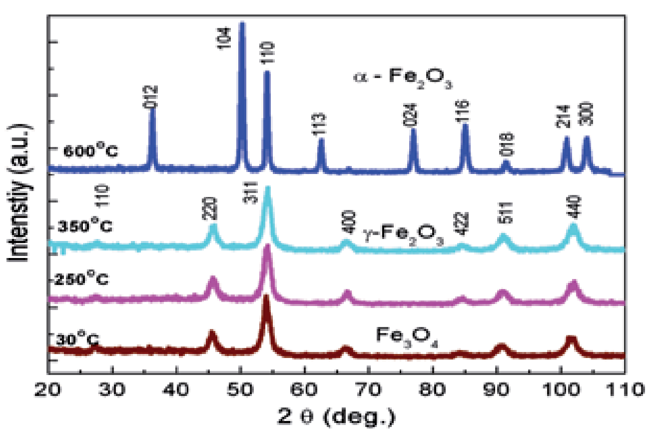


Figure 2: XRD patterns of uncoated Fe_3O_4 nanoparticles heat-treated at different oxidation temperatures of 30, 250, 350, and 600 °C in air

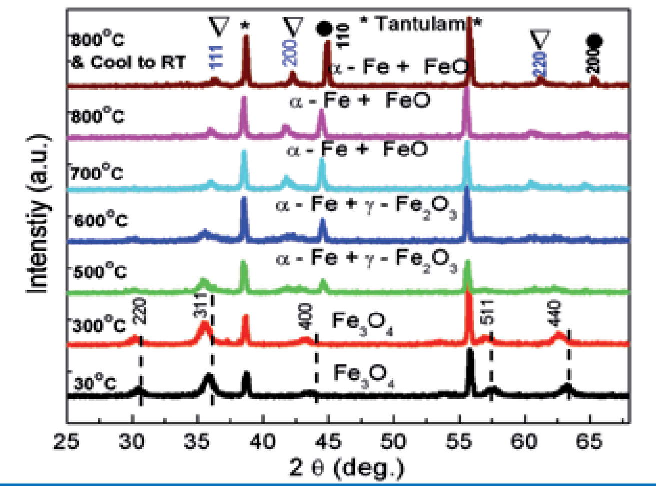


Figure 3*:* In situ XRD patterns of oleic acid coated Fe_3O_4 nanoparticles annealed in vacuum and cooled it back to room temperature. Dashed line: Fe_3O_4, open triangular: FeO, and solid circle: α–Fe phase

systematically from room temperature to 1000ºC by maintaining the vacuum of 10^{-5} mbar throughout the experiment. In situ XRD pattern is collected at the desired temperature using Philips – X'pert MPD system. Figure 1 shows the in situ XRD pattern of uncoated Fe_3O_4 nanoparticles heated at different temperatures of 30, 300, 400, 500, 600, 700, 800, 900, 1000ºC and cooled back to room temperature. The diffraction peaks of (220), (311), (400), (422), (511) and (440) are observed in the temperature range of 30-600ºC, which can be indexed to cubic spinel structure with Fe_3O_4 phase (JCPDS No.:89-0691). During heating all the observed peaks become narrower with high intensity and shift towards the lower angle. The first change can be attributed to the increase in particle size due to coalescence phenomenon of particles by solid state diffusion where the system reduces its free energy by reducing the surface area of the nanoparticles. The later is attributed to the lattice expansion with increasing temperature. On further heating (>700ºC), Fe_3O_4 decomposed in to γ-Fe_2O_3 and FeO phases [additional reflections from (110), (200) and (220)] and continuous up to 1000ºC. At 1000ºC and cooled it back to room temperature a trace of γ–Fe [reflection from (111) and (200)] and α–Fe [reflections from (110) and (200) planes] are observed along with major phases of γ-Fe_2O_3 and FeO. To understand the role of vacuum on the phase transition of Fe_3O_4, we annealed the same sample at different temperature for two hours. under air atmosphere up to 600ºC. The XRD pattern (using Cr-K_α) of uncoated Fe_3O_4 nanoparticles annealing in air medium is shown in Figure 2. Since Fe^{2+} ions are more sensitive to oxidation, surface ferrous ions get oxidized to ferric ions leading to the formation of maghemite (g-Fe_2O_3 phase) in the temperature range 250 to 350ºC. At 600ºC, the rhombohedral crystal structure of hematite (α-Fe_2O_3) phase is evident from the characteristic peaks of (012), (104), (110), (113), (024), (116), (018), (214) and (300). Thus, uncoated Fe_3O_4 is not converted into hematite, (α-Fe_2O_3) under vacuum thermal annealing up to 1000ºC, due to lack of oxidative atmosphere.

In-situ high temperature XRD patterns of oleic acid coated Fe_3O_4 nanoparticles during similar annealing conditions up to 800ºC and cooling it back to room temperature is shown in Figure 3. In the temperature range RT-300ºC, the observed diffraction peaks from (220), (311), (400), (511) and (440) planes are assigned to cubic spinel structure of Fe_3O_4. Surprisingly, in the temperature range, 500-800ºC and cooling it back to Room Temperature, the XRD pattern matches well with α-Fe, with additional peaks from (110) and (200) plane. Above 700ºC, apart from characteristic peaks of α-Fe, the additional very low intensity peaks of (111), (200) and (220) indicate the presence of FeO phase. Here the question to be addressed is as follows: (1) What is the role of surfactant in the reduction of oleic acid coated Fe_3O_4 nanoparticles during vacuum annealing? (2) Will the same reduction takes place under air annealing? To answer the first question we have done the TGA coupled mass spectrometer under inert argon atmosphere to avoid the oxidative atmosphere. The simultaneous thermo gravimetric analysis (TGA), differential scanning colorimetery (DSC) and mass spectra (MS) of oleic acid coated Fe_3O_4 (Figure 4) shows a three-step weight loss along with a few endothermic peaks. The initial weight loss of about 4% in the temperature range of 100-200ºC is due to decomposition of moisture content in the sample. The second weight loss occur at 231ºC due to breaking of weakly bonded functional group (COOH) from secondary and primary surfactant layer. CO_2 fractions (m/e ~ 44, where m is the atomic mass and e is the ion charge) starts to evolve before 200ºC, reaches their maximum at around 240 and 330ºC. H_2 (m/e ~2) becomes the apparent gas product from linear hydrocarbon chain along CO (m/e ~28) after 320ºC and reaches their maximum at 400ºC accompanied by a little water vapor possibly produced by the reaction between H_2 and CO_2. In the temperature range of 300 –500ºC, the weight loss was nearly 20% and is attributed to the oleic acid decomposition. Third weight loss of 12% at 600-800ºC is due to the removal of oxygen from the lattice by carbon and thereby evolving CO and CO_2 effluents from the sample reveals the reduction of Fe_3O_4 to α-Fe with small amount of FeO. These

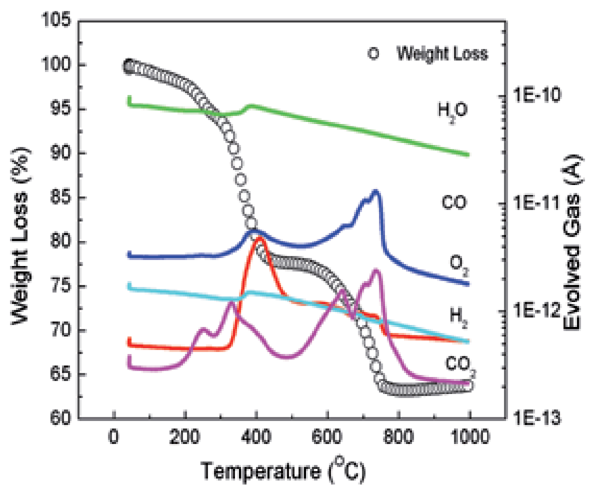


Figure 4: Thermo gravimetric curve and mass spectroscopic curves of oleic acid coated Fe_3O_4 nanoparticles under inert argon atmosphere

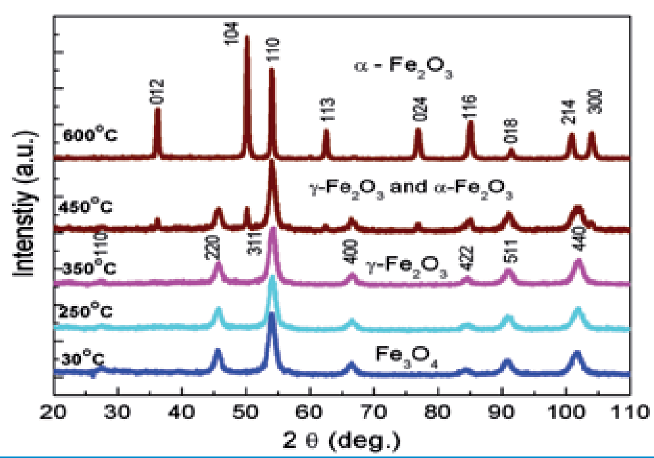


Figure 5: XRD patterns of oleic acid coated Fe_3O_4 nanoparticles heat-treated at different oxidation temperatures

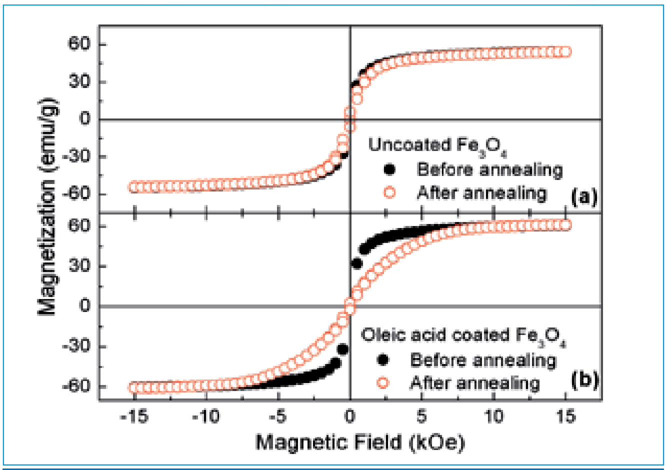


Figure 7: Room temperature hysteresis loops of (a) uncoated and (b) oleic acid coated Fe_3O_4 nanoparticles in the fields up to ± 15 kG

results show that carbon from the oleic acid has a major role in reducing γ-Fe_2O_3 to α-Fe at 600°C during vacuum annealing and consistent with the XRD data where α-Fe starts precipitating at 500°C. The interaction between the head group of the oleic acid and the oxygen in Fe_3O_4 is expected to cause a weakened bonding that could have resulted in lower activation energy for the reduction of surfactant coated nanoparticles during vacuum annealing. Similarly nonmagnetic α-Fe_2O_3 nanoparticle is observed as an end product at 600°C when the oleic acid coated Fe_3O_4 nanoparticles is annealed under oxidative atmosphere (Figure 5). In oxidative medium too, above 300°C both C and H_2 are released from the oleic acid. These evolved (H_2 and C) gases will make use of freely available oxygen from the atmosphere instead of taking it from the sample, as the former is energetically favorable at atmospheric pressure. Therefore, the γ-Fe_2O_3 to α-Fe_2O_3 conversion started at 450°C and is fully complete at 600°C without formation of metallic Fe. The schematic of various phase transformation under air and vacuum in coated and uncoated samples are shown in Figure 6.

Figures 7a and 7b shows the hysteresis loop before and after vacuum thermal annealing of coated and uncoated Fe_3O_4 nanoparticles respectively. When particles are single domain (for Fe_3O_4 ~ 28 nm) they exhibit ferrimagnetic behavior. Before thermal annealing, both the samples show superparamagentic behavior with zero coercivity and zero remnance. After vacuum thermal annealing, oleic acid coated Fe_3O_4 nanoparticles shows minimum hysteresis of 50 G in their magnetization data at 290 K. After annealing at 1000°C, the uncoated Fe_3O_4 sample is converted from ferri to ferromagnetic with coercivity of 200 G. However, the saturation magnetization of the sample remains the same due to dominance of γ-Fe_2O_3. In case of oleic acid coated Fe_3O_4 nanoparticle after vacuum annealing, the sample is converted from ferrimagnetic to ferromagnetic. However, the saturation magnetization field after annealing was much higher (9 kG against 3 kG) due to the presence of α-Fe and FeO phase. Before and after vacuum thermal annealing, saturation magnetization of oleic acid coated Fe_3O_4 nanoparticle is around 61 emu/g at 290 K. Even though we observed the α-Fe starts precipitating from 500°C, the magnetization shows only 1/3 of its bulk value of 220 emu/g. The presence of FeO phase, which is paramagnetic at room temperature and considerable mass of carbon from oleic acid decomposition seams to be the reason for the lower net saturation magnetization after vacuum thermal annealing.

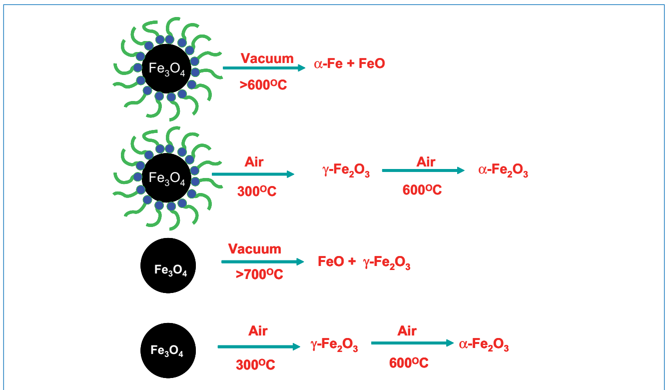


Figure 6: Schematic of the phase transitions in coated and uncoated magnetite nanoparticles under vacuum and air annealing

In conclusion our results demonstrate the important role of surfactant monolayer on the reduction of surface functionalized Fe_3O_4 ferrite nanoparticles during annealing. The interaction between the head group of the oleic acid and the oxygen in Fe_3O_4 is expected to cause a weakened bonding that could have resulted in lower activation energy for the reduction in oleic acid coated ferrite nanoparticles compared to uncoated one. This could be the plausible reason for the precipitatation of α-Fe during vacuum annealing in surfactant coated system. This work opens up possibilities for adjusting the chemical identity and magnetic properties of ferrite nanoparticles and facilitates better utility of these ferrite nanoparticle in emerging technologies.

(Reported by S. Ayyappan,
Non-Destructive Evaluation Division)

Conference/Meeting Highlights

Mid-Year meeting of the Materials Research Society of India Council

Dr.T.Ramasami, Secretary, Department of Science and Technology, members of the Materials Research Society of India Council with Dr.Baldev Raj, Director, IGCAR and other senior colleagues of the Centre

The Mid–Year meeting of the Materials Research Society of India(MRSI)- Council, to deliberate on the formulation of a five year Road Map for MRSI was held on Saturday, April 3, 2010, at IGCAR, Kalpakkam. The meeting was chaired by Dr. T. Ramasami, Secretary, Department of Science & Technology and President, MRSI, with several senior functionaries present: Dr. Baldev Raj, Director, IGCAR and Vice-President MRSI, Prof. S.B. Krupanidhi, General Secretary MRSI, Council members and Chairmen of various MRSI Subject groups and Regional Chapters. Several senior materials scientists from IGCAR also participated in the day-long meeting.

Dr. Ramasami elicited the viewpoints of Council members and invitees, both on the content of current activities and on the Structure of MRSI, to take this important Professional body forward towards facilitating front-ranking research in the important area of Materials Science. Several suggestions on, new initiatives to be taken up, starting of new subject groups, merger of a few related subject groups and conduct of thematic workshops, were made. An important recommendation of the meeting pertains to the formation of new task forces with the explicit purpose of enhancing the MRSI linkage with Industry, Academic Institutes, Research laboratories and for Societal benefits.

Dr. Ramasami, indicated that based on these deliberations, an action plan for implementation by MRSI would be prepared, which would serve as a valuable scientific input towards the formulation of XII- plan proposals. The MRSI- Council members also visited the PFBR site and some of the research laboratories, and expressed their appreciation for the nice hosting of the meet at Kalpakkam.

(Reported by C. S. Sundar, Chairman, MRSI-Kalpakkam Chapter)

Eighth International Conference on Barkhausen Noise and Micromagnetic Testing (ICBM8)

February 11, 2010

Dr. Baldev Raj, Director, IGCAR, inaugurating the ICBM on February 11, 2010

Eighth International Conference on Barkhausen Noise and Micromagnetic Testing (ICBM8) was organised jointly by IGCAR, BRNS and AERB during February 11-12, 2010. During the inaugural function, Dr. T. Jayakumar, Chairman, ICBM8 and Director, MMG, gave the welcome address and Mr. Lasse Suominen, Chairman, ICBM Organisation and President, Stresstech Oy, Finland spoke about ICBM serial conference. Dr. Baldev Raj, Director, IGCAR, inaugurated the conference and in his address during which he stressed the need for increased use of Barkhausen noise and micromagnetic techniques by the industry for materials evaluation and stress measurement applications. He emphasized the need for evolving standards for magnetic Barkhausen emission techniques for different applications and forging international collaborations among different research groups working in this field. Dr. B.P.C. Rao, Co-Chairman, ICBM8 explained about the conference and Dr. C.K. Mukhopadhyay, Convener, ICBM8 proposed the vote of thanks.

The conference was attended by fifty scientists, engineers and scholars from various DAE units, IIT Madras, BHU-IT, SERC, DMRL, NML, CPRI, Mercantile Marine Department etc., and sixteen foreign delegates from nine countries including Stresstech Oy, Finland; Fraunhofer-IZFP, Germany; University of Defence and Institute of Physics, Czech Republic; Tampere University of Technology and University of Oulu, Finland; Iwate University, Japan; Atomic Energy Research Institute, Hungary; Comisión Nac de Energía Atómica, Argentina and Newcastle University, UK.

In the conference, six eminent international experts including Dr. G.Dobman, IZFP, Germany, Dr. B.A. Shaw, Newcastle University, UK and Dr. Evan Thomas, Institute of Physics, Czech Republic delivered invited lectures covering various aspects of Barkhausen noise and micromagnetic testing. A total of twenty two contributory papers covering microstructural characterization; residual stress measurements; damage assessment and industrial applications were presented in six technical sessions. A technical visit to FBTR and NDED was organized for the ICBM delegates. The concluding session of ICBM was held on February 12, 2010. A panel consisting of Dr. T. Jayakumar, Dr. G. Dobmann, Dr. S. Sitaramu, Director, CPRI, Bengaluru, Dr. B.A. Shaw and Mr. Lasse Suominen summed up the deliberations in ICBM8 and highlighted the need for round robin tests; separation of stress and microstructure effects on MBE signal; consideration of material properties and probabilistic fracture for better understanding of MBE signals; increased use of multi-parameter approaches and neural networks. Mr. Lasse Suominen announced that the ICBM9 would be held in Czech Republic in 2011.

(Reported by T. Jayakumar, Chairman, ICBM8)

Conference/Meeting Highlights

Instrument and Control Systems for Radioactive Laboratories (ICRL)

January 29, 2010

One day meet on Instrumentation & Control systems for Radioactive Laboratories (ICRL 2010) was held on January 29, 2010, in Raja Ramanna Auditorium, Kalpakkam, under the auspices of Post Irradiation Examination Division (PIED), GRIP, MMG.

Welcome address and genesis of ICRL 2010 was given by Shri K.V. Kasiviswanathan, AD, GRIP. The one day meet was inaugurated by Shri R. Natarajan, Director, RpG. Shri N.G.Muralidharan proposed the vote of thanks.

Shri R. Natarajan in his inaugural address stressed the need and importance of the instrumentation in the reprocessing laboratories and other radioactive laboratories. Since there are going to be more number of reactors (thermal and fast) in the coming years to enhance the contribution of nuclear energy, the quantity of fuel to be reprocessed would be more (in tonnes). The reprocessing plant will handle more fuel in a complex pipe lines inside the hot cell which will have high activity and high gamma dose the need of instrumentation control has become a vital and important one. For example monitoring of Plutonium in air, neutron monitoring system with less error, computer based system for plants and Plutonium monitoring system for on line monitoring in the pipe lines are the some of the areas where the instrumentation and control system plays a vital role. He also stressed the need for details required for obtaining the clearance from the safety authorities. At present no standard is available for such equipments and all are under development. Further he said that this one day meet is only a start and ignition to have big events in future to discuss and to have more deliberation with more participants working in the areas of instrumentation and control in our Department.

Shri R. Natarajan, Director, RpG &
Shri K. V. Kasi Viswanathan, AD, GRIP, during the meeting

Seven invited talks by the Instrumentation & Control experts in various radioactive facilities of IGCAR and BARC were presented during the one day meet. About sixty five participants including the young engineers involved in instrumentation and control of radioactive laboratories were attended the one day meet.

Forenoon session was chaired by Shri P. Kalyanasundaram, AD, FRTG where invited talks were presented.

(Reported by P. Kalyanasundaram, FRTG)

One Day Workshop on Materials Characterisation using NDE Techniques (MCNT-2010)

February 10, 2010

Dr. D.K. Bhattacharya, Acting Director, Central Glass Ceramic Research Institute, Kolkata releasing the proceedings of MCNT-2010 in the presence of
Dr. G. Dobmann, IZFP, Germany and Dr. T. Jayakumar, Chairman, MCNT-2010 and other colleagues of the Centre

A pre-conference workshop on 'Materials Characterisation using NDE Techniques (MCNT-2010)' was organised jointly by IGCAR, Board of Research in Nuclear Sciences, Atomic Energy Regulatory Board and Materials Research Society of India, Kalpakkam chapter on February 10, 2010 at SRI Convention Centre, Anupuram. This workshop was part of the eighth International Conference on Barkhausen Noise and Micromagnetic Testing (ICBM8) which was held at Anupuram during February 11-12, 2010. During the inaugural function of MCNT-2010, Dr. T. Jayakumar, Chairman, MCNT-2010 and Director, MMG, IGCAR gave the welcome address. Dr. G. Dobmann, Deputy Director, Fraunhofer-IZFP, Saarbrücken, Germany inaugurated the workshop. During the inaugural address, he highlighted the lead role played by NDE techniques during manufacturing stages and towards assessment of damage in operating components. Dr. D.K. Bhattacharya, Acting Director, Central Glass and Ceramic Research Institute (CGCRI), Kolkata, released the workshop proceedings and addressed the delegates. Dr. B. P. C. Rao, Co-Chairman, MCNT-2010, explained about the workshop. Dr. C. K. Mukhopadhyay, Convener, MCNT-2010 proposed the vote of thanks.

There were nine lectures in this workshop covering various aspects of materials characterisation using NDE techniques like, micromagnetic, ultrasonic, eddy current, acoustic emission, positron annihilation, X-ray diffraction, infrared thermography and in-situ metallography for characterization of microstructures, residual stresses, deformation, damage and fracture, in addition to a lecture on 'Importance of microstructure and residual stress for materials characterization' delivered by Dr. D.K. Bhattacharya. The faculty of MCNT-2010 was drawn from IZFP, Germany; CGCRI, Kolkata, IPR, Gandhinagar and IGCAR, Kalpakkam. The workshop was attended by seventy scientists and engineers from R&D organizations and industry including delegates one each from Tampere University of Technology and University of Oulu, Finland; Iwate University, Japan and Comision Nac de Energia Atomica, Argentina.

(Reported by C.K. Mukhopadhyay, Convener, MCNT-2010)

News and Events

Prof. C. N. R. Rao visits the Centre

March 12 - 13, 2010

Prof.C.N.R.Rao, National Research Professor, Honorary President and Linus Pauling Research Professor, Jawaharlal Nehru Centre for Advanced Scientific Research and Honorary Professor, Indian Institute of Science, Bengaluru while delivering the Dr.Homi J.Bhabha eminent lecture

Prof.C.N.R.Rao, National Research Professor, Honorary President and Linus Pauling Research Professor, Jawaharlal Nehru Centre for Advanced Scientific Research and Honorary Professor, Indian Institute of Science, Bengaluru visited the Centre during March 12-13, 2010 accompanied with his wife, Mrs.Indumati Rao, Honorary Coordinator, Multimedia Group, Education Technology Unit, JNCASR. Prof. C. N. R. Rao delivered the “Eminent Lecture” as a part of the lecture series organised to commemorate the birth centenary of Dr. Homi. J. Bhabha, on the topic “Graphene and Beyond”. This talk was well attended and appreciated.

Prof. C. N. R. Rao, with his keen passion to inspire the young minds, presented an interesting lecture on "A Celebration of Chemistry" followed by an equally inspiring interactive session on "Understanding Chemistry" by Mrs. Indumati Rao to the students from the schools of Kalpakkam. The students relished the lecture and were happy to have had an opportunity to interact with such eminent scientists. Prof.C.N.R.Rao and Mrs.Indumati Rao later visited laboratories in Electronics and Instrumentation Group, Materials Science Group and the construction site of PFBR.

Prof.C.N.R.Rao and Mrs. Indumati Rao with Dr. Baldev Raj, Director, IGCAR, senior colleagues of the Department and children from schools of Kalpakkam

News and Events

MoU signed between IGCAR and NUT, Japan

January 11, 2010

MoU being signed between Nagaoka University of Technology, Japan and IGCAR by Dr. Baldev Raj, Director, IGCAR in the presence of Prof. Masakazu Okazaki, on January 11, 2010

A Memorandum of Understanding (MoU) for academic, educational and research collaboration was signed between IGCAR and Department of Mechanical Engineering, Nagaoka University of Technology, Japan on January 11, 2010. The MoU envisages collaboration between the two organizations in areas related to materials science, engineering and technology to promote the advancement of academic, educational and research activities of mutual interest. Under this MoU, the two institutions agreed to (i) exchange of professors, research scientists and students (ii) collaborative research on scientific and technological subjects (iii) organise scientific and technological meetings, symposia and lectures, and (iv) exchange academic findings, publications and educational information. The specific technical topics identified for collaboration include (i) creep, fatigue and creep-fatigue interaction and thermo-mechanical fatigue of advanced ferritic steels and austenitic stainless steels, (ii) thermo-physical characteristics of advanced engineering materials, (iii) modeling thermomechanical processing and mechanical behavior of engineering materials, (iv) study of micro-chemistry and micro-structure using advanced electron-optical techniques, (v) development of coatings for corrosion and tribological applications, (vi) characterization of materials using advanced NDE techniques and (vii) development of signal analysis and image processing methodologies and knowledge based systems for materials characterization.

(Reported by T. Jayakumar, MMG)

XXV DAE Sports Meet-Table Tennis at Kalpakkam

February 23, 2010

As part of XXV DAE Sports Meet, Table Tennis meet was organized at Indoor Auditorium, Kalpakakam from February, 8-12, 2010. The DAE teams from various parts of India took part in the meet with zeal and spirit. The meet was inaugurated by Shri Prabhat Kumar, Project Director, BHAVINI and he enlightened the gathering with his address. Dr. B. Venkatraman, Chairman, Steering Committee welcomed the gathering. Dr. Hasan Shaikh, Chairman, Tournament Committee presented the vote of thanks.

Shri Prabhat Kumar, Project Director, BHAVINI, inaugurating the XXV DAE Sports Meet in Table Tennis

The results:

Winner Team (Men): Dwaraka; Winner Team (Ladies): Ellora
Winner Team (Veteran): Ellora; Fair Play: Pushkar

Shri K. Ramamurthy, Station Director, Madras Atomic Power Plant and Shri A. S. L. K. Rao, Chairman, Kalpakkam Games Promotion Council (KGPC) presided over the closing ceremony and gave away the prizes.

(Reported by S. Thirunavukkarasu, KGPC)

News and Events

Meeting of Scientific Advisory Committee to Prime Minister

February 12, 2010

Prof. C. N. R. Rao, Chairman, Scientific Advisory Committee to Prime Minister, National Research Professor, Honorary President & Linus Pauling Research Professor, JNCASR, Dr. T. Ramasami, Secretary, Department of Science and Technology, Dr. Srikumar Banerjee, Chairman, AEC & Secretary, DAE and other members of the Scientific Advisory Committee to Prime Minister with Dr. Baldev Raj, Director, IGCAR

The meeting of the Scientific Advisory Committee to Prime Minister was held at IGCAR, Kalpakkam on February 12, 2010. The meeting was chaired by, Prof.C.N.R.Rao, Chairman, Scientific Advisory Committee to Prime Minister, National Research Professor, Honorary President & Linus Pauling Research Professor, JNCASR. Distinguished members, Dr. P. Rama Rao, Dr. Srikumar Banerjee, Prof. P. Balaram, Dr. M. K. Bhan, Dr. A. K. Sood, Prof.Bikash Sinha, Dr. T. Ramasami, Dr. Vijay Kumar Saraswat, Prof. Sujatha Ramadorai, Prof. B. K. Thelma, Prof. D. V. Khakhar, Prof. Mustansir Barma, Prof. M. M. Sharma, Dr. Ashok Jhunjhunwala, Prof. V .K. Singh and Dr. K. Vijayaraghavan attended the meeting. The expert committee meeting for combustion was also conducted prior to the meeting. The dignitaries visited various facilities of the Centre and construction site of PFBR.

Visit of Dignitaries

Team from University of North Texas with Dr.Baldev Raj, Director, IGCAR and other senior colleagues of the Centre

A team of academicians from the University of North Texas led by Dr. Rajarshi Banerjee, visited the Centre on January 7, 2010. The team held discussions with Dr.Baldev Raj, Director, IGCAR and other senior colleagues from the Metallurgy & Materials and Materials Science Groups. They visited the laboratories in Metallurgy & Materials and Materials Science Groups.

Dr. M. R. Srinivasan, former Chairman and Member, AEC visited the Centre on January 6, 2010. During the visit he went around the Virtual reality center, Simulator and High end computing facilities at Computer Division, Safety Grade Decay Heat System(SADHANA) at Fast Reactor Technology Group, Sodium fire facility at Safety Group and construction site of PFBR.

Shri S. A. V. Satyamurthy, Head, Computer Division giving details to Dr. M. R. Srinivasan, former Chairman and Member, AEC

Visit of Dignitaries


Dr. Baldev Raj, Director, IGCAR with the visitors from United Kingdom and Dr.Hajime Hatano, Chairman, ISO TC/SC 135 and Professor, Department of Applied Electronics, Tokyo University of Science, Japan

A team of academicians from United Kingdom, comprising of Dr.Timonthy James Abram, Professor in Nuclear Fuel Technology, University of Manchester, Dr.Michael Edward Fitzpatrick, Chair, Materials Fabrication and engineering, The Open University, Milton, Dr.Robin William Grimes, Director, Centre for Nuclear Engineering and Professor of Materials Physics, Imperial College and Mr.Richard Nicholas Buttrey, Diplomat, Second Secretary, Science and Innovation, British High Commission and Dr.Hajime Hatano, Chairman, ISO TC/SC 135 and Professor, Department of Applied Electronics, Tokyo University of Science, Japan visited the Centre during January 7-8, 2010. The team held discussions with DAC members of the Centre and visited Fast Breeder Test Reactor, Hot Cells and Non-Destructive Evaluation Division and the construction site of PFBR.


Dr. Baldev Raj, Director, IGCAR with Dr.Luc Vanden Durpel, Scientific Director and Mr. Patrick Tuyssier, Director, Markerting and Strategy from AREVA

Dr. Luc Vanden Durpel, Scientific Director and Mr. Patrick Tuyssier, Director, Marketing and Strategy, AREVA visited the Centre on January 7, 2010. After meeting Dr. Baldev Raj, Director, IGCAR and holding discussions with the DAC members they were taken around to visit the Fast Breeder Test Reactor, the construction site of PFBR and Nuclear Desalination Development Plant.

Dr.Rusi P.Taleyarkhan, Professor, Nuclear Engineering, Purdue University visited the Centre on January 8, 2010 and gave a lecture on “Tensioned Metastable Fluid Technology for Transformational Nuclear Particle Sensors, Materials Synthesis and Actinide Transmutation”. He later visited the Fast Breeder Test Reactor, laboratories in the Materials Sciences Group and the construction site of PFBR.


Dr. Rusi P.Taleyarkhan,Professor,Nuclear Engineering, Purdue University with Dr.Baldev Raj, Director, IGCAR


Dr. Eberhard Diegle, Fusion for Energy, Barcelona along with a senior colleague of the Centre

Dr.Eberhard Diegle, Fusion for Energy, Barcelona, Spain visited the Centre on January 8, 2010. After meeting Dr.Baldev Raj, Director, IGCAR and other senior colleagues from the Metallurgy and Materials Group, he visited the construction site of PFBR.

Visit of Dignitaries

A delegation from Fermilab led by Dr. Piermaria Oddone, Director, Fermilab visited the Centre on January 16, 2010. After holding discussions with the DAC members, the team visited the Accelerator & Low temperature laboratories in the Materials Sciences Group, laboratories in the Safety Group, the Fast Breeder Test Reactor and the construction site of PFBR.

Delegation from Fermilab at FBTR Control Room along with colleagues of the Centre

Prof. Eberhard Roos, Dr. Andreas Klenk and Dr. Xaver Schueler from MPA, Stuttgart, Germany with Dr. Baldev Raj, Director, IGCAR and Dr.T.Jayakumar, Director, Metallurgy and Materials Group

Prof.Eberhard Roos, Dr.Andreas Klenk and Dr.Xaver Schueler from MPA, Stuttgart, Germany visited the Centre on January 22, 2010. After meeting Dr.Baldev Raj, Director, IGCAR the team visited Structural Mechanics Laboratory and construction site of PFBR. The team also had discussions with colleagues from Metallurgy & Materials and Reactor Engineering Groups on the status of collaborative projects.

Dr. Shchedrovitskiy Petr, Dr. Alexandar Bychkov and Dr. Igor Leshukov from ROSATOM, Russia visited the Centre on February 2-4, 2010. After meeting the DAC members, the visitors were taken around to visit Fast Breeder Test Reactor, Laboratories in Metallurgy and Materials, Chemistry, Safety, Electronics & Instrumentation, Materials Science and Reactor Engineering Groups. They also visited the construction site of PFBR.

Dr. Baldev Raj, Director, IGCAR, with the visiting delegation from ROSATOM and other colleagues from the Centre

Dr.Baldev Raj, Director, IGCAR, Prof.Bikash Sinha, Homi Bhabha Professor and former Director, VECC, Kolkata and Dr.C.S.Sundar, Director, Materials Science Group standing besides the bust of Dr.Raja Ramanna

Prof. Bikash Sinha, Homi Bhabha Professor and former Director, VECC, Kolkata, visited the Centre on February 11, 2010 and delivered a lecture to the colleagues of the Centre.

Visit of Dignitaries

Shri Y.S.Mayya, Chairman & Managing Director and a team from Electronics Corporation of India visited the Centre on March 6, 2010. After meeting Dr.Baldev Raj, Director, IGCAR, they discussed with senior colleagues of the Centre. An MoU was signed for collaboration between IGCAR and ECIL. They later visited the facilities in the Computer Division.

Shri Y. S. Mayya, Chairman and Managing Director, Electronics Corporation of India with Dr. Baldev Raj, Director, IGCAR during the signing of MoU

Dr.Andre Phillippe Maisseu, President, World Council of Nuclear Workers(WONUC) & Chief Editor, International Journal of Nuclear Engineering Science and Technology, undertook a visit to our Centre on March 8, 2010. After meeting the Director and DAC members, Dr.Maisseu visited the Fast Breeder Test Reactor and laboratories in the Fast Reactor Technology Group. Dr.Maisseu gave a special lecture to the colleagues of the Centre.

A delegation from the Czech Nuclear Power visited the Centre during March 9-10, 2010. The team visited the Fast Breeder Test Reactor, Laboratories in Non Destructive Evaluation Division and Hot cells, laboratories in Fast Reactor Technology Group and Structural Mechanics Laboratory at IGCAR. The team also visited the Madras Atomic Power Station and the construction site of PFBR.

Dr. Tomas Huner, leader of Czech Nuclear Power delegation with Shri S.C.Chetal, Director, REG

Awards & Honours

- Dr. Baldev Raj, Director, IGCAR has been invited to be a member of the committtee for selecting the Australia India Science & Technology Research Award on "Energy Generation in a Low Carbon Future" instituted by Australian Academy of Technological Sciences and Engineering in association with Australian Government's Australia India Council

- Dr. Baldev Raj, Director, IGCAR has been nominated as External Expert, Peer Review Committee for the Cluster – Chemical Sciences, Group I: Chemical Materials & Energy, Council of Scientific & Industrial Research, New Delhi (2010)

- Dr. Baldev Raj, Director, IGCAR delivered DAE Raja Ramanna Lecture in Physics, Jawaharlal Nehru Centre for Advanced Scientific Research, Bengaluru (2009)

Dr. M. Sai Baba, Convenor, **Editorial Committee Members: Shri Utpal Borah, Dr. K. Ananthasivan, Dr. K.K. Satpathy, Shri N. Desigan, Shri S. Varadharajan, Dr. Vidya Sundararajan, Shri C. Jayakumar and Shri J. Daniel Chellappa.**

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