# IGC newsletter

ISSN 0972-5741 Volume 65 July 2005


# From the Director's Desk



## Coherent Synergy with Academia-Research Institutes-Industry to Realize Mature Technology for Fast Breeder Reactors

### Introduction

Realising the vision of transforming our country into a technologically and economically advanced Nation, necessitates a commensurate growth in energy generation. To sustain the anticipated growth rate of GDP, to enable the required industrial growth, and to ensure improved standard of living, a nearly 8 times increase in energy generation is essential in the next four decades. Considering the postulated energy demand by 2050 and the availability of fuel resources in-land, DAE has estimated a contribution of at least 25% from nuclear energy. A substantial increase in the contribution of nuclear energy to the power generation in the country can only be achieved through the maximum utilization of the limited uranium resources and the vast thorium reserves in the country. Towards enabling this, fast breeder reactors (FBRs) are becoming an inevitable route towards providing energy security to the Nation.

The Indian FBR program started with the 40 MW(t) Fast Breeder Test Reactor (FBTR) at Kalpakkam. The successful design, construction and operation of FBTR, has been an important milestone in demonstrating the technological viability of FBRs. A burn-up of 148,000 MWd/tonne for the unique high plutonium based carbide fuel, successful reprocessing of fuel that has seen burn-up of 100,000 MWd/tonne, and mastering the sodium handling technology including extended continuous operation of the sodium pumps without maintenance, are just a few major technological highlights of fast reactor programme. This success has paved the way for stepping into the commercial phase of the second stage of the nuclear power generation programme. Construction of a 500 MW(e) Fast Breeder Reactor Project (PFBR) has commenced at Kalpakkam, and will be commissioned before September 2010.

The keys to the success of our FBR programme are improved design with longer plant life, improved safety, higher breeding gain, and effective closing of the fuel cycle. This means that continued emphasis has to be laid on R&D in every aspect of FBR technology. The primary mandate of Indira Gandhi Centre for Atomic Research (IGCAR) is to create, sustain and nurture comprehensive multi-disciplinary R&D programmes addressing every aspect of design, material development, equipment development, chemistry, reprocessing, economy and efficiency, and safety, for FBRs. This holistic approach, with intense synergism with other units of DAE, particularly Bhabha Atomic Research Centre (BARC) and Nuclear Fuel Complex (NFC), is the foundation for the success of FBTR. Vigorous pursuit of this collaborative approach, with a much larger ambit, including many academic and research institutions, and indigenous industries, has been crucial in accelerating the pace for finalizing the design and demonstration of manufacturing technology for 500 MW(e) FBR. Some of these linkages are highlighted in this article.

***... Vigorous pursuit of this collaborative approach, with a much larger ambit, including many academic and research institutions, and indigenous industries, has been crucial in accelerating the pace for finalizing the design and demonstration of manufacturing technology for 500 MW(e) FBR. ...***

In the process of developing expertise in areas related to the technology for fast reactors, IGCAR has also developed expertise in many related areas of science and engineering, not to mention world class infrastructure, a few of them unique in India. Because of these strengths, many Indian organizations and institutes, encompassing academia, research centres, and those involved in key national sectors including defence and space, periodically utilize the expertise and infrastructure at IGCAR. These interactions, besides aiding the growth of science and technology of the entire Nation, have also resulted in providing crucial inputs to the development of FBR technology. Over the years, scope of such interactions have considerably widened and deepened, a testimony to the mature and comprehensive approach to R&D at IGCAR. It is no surprise that today IGCAR is a partner to the Department of Science and Technology (DST) of Government of India, and Council of Scientific and Industrial Research (CSIR) in some of their key initiatives. International collaboration with reputed laboratories in niche areas has also proved mutually beneficial. These inter-laboratory interactions are many and varied; only a few examples are included in this essay. The individual interactions of IGCAR scientists with their counterparts in other academic and research laboratories, a hallmark of any vibrant research group and an important facet of the science and technology ethos of the country, have been extremely rewarding and enriching.

## Academia and Research Institute Interactions

In order to meet the challenging tasks in our indigenous mission programme, a conscious effort has been made, over the decades, to network a vibrant academia-research institute-industry interaction, towards finding solutions for FBR technology. Apart from the contributions from eminent faculty members, the inputs provided by the dynamic and enthusiastic students have been commendable. Thus human resource development has been one of the areas of emphasis in the management philosophy of the Centre. Besides, it has also been realised that as a premier R & D Centre with state-of-the art facilities, IGCAR is well placed to contribute to enhancement of science and technology education in India.

A variety of approaches to strengthen a vibrant interaction with academic and research institutes have been adopted by IGCAR. The various modes of interaction include participation of selected students to pursue postgraduate research at IGCAR, sponsored research projects, collaborative projects, and by organizing vocational training courses and workshops. Also, a few scientists from IGCAR have been

***.. The individual interactions of IGCAR scientists with their counterparts in other academic and research laboratories, a hallmark of any vibrant research group and an important facet of the science and technology ethos of the country, have been extremely rewarding and enriching. ...***

invited as members of the Board of Studies by academic institutions, like Anna University, Annamalai University, Sathyabama Deemed University and PSG College of Technology, to enhance their quality of education. Many scientists from IGCAR have also benefited from interactions with academic institutions like Indian Institutes of Technology (IITs), Indian Institute of Science (IISc.), Banaras Hindu University, Anna University, Madras University, etc., to acquire higher qualifications.

## Collaborative Research Projects

More than 80 sponsored projects have already been completed in collaboration with 23 institutes, including many premier academic and R&D institutes. Many projects are sponsored by IGCAR, while some of the projects are sponsored by Board of Research in Nuclear Sciences (BRNS). Many of these projects have led to the augmentation and enhancement of infrastructure at the collaborating laboratories utilizing the project fund; the benefits to the students and the research community thus go beyond the boundaries of these specific projects. Most projects are in areas vital to FBR and reprocessing programmes, be it support to robust design, detailed materials characterization, establishing and validating new technologies, or search for new and better processes. Majority of the projects with IIT Madras, in support of design, involve development of models, and theoretical and computer code development. Some of the projects had also experimental components for which infrastructure available was used, or specifically built with the project fund. Examples are: buckling investigations of inner vessel and main vessel, dynamic experiments on core support structure, studies on thermal striping, structural integrity assessment of control plug and sodium piping, seismic qualification studies on Control and Safety Rod Drive Mechanism (CSRDM), structural design of reactor vault, geo-technical characterization of 500 MW(e) FBR site, mathematical model for sodium combustion in leak collection tray, and various thermal-hydraulics studies. Projects with IISc., Bangalore relating to various aspects of 500 MW(e) FBR design are equally important. These include review of Design Basis Earthquake for 500 MW(e) FBR site, seismic response of sodium pipelines, structural reliability analysis of core support structures, coalescence of drops in centrifugal contactors, and experimental and analytical study on the reinforced cement concrete beam column joints with/without fibers under cyclic loading.

Among the research institutes, Terminal Ballistic Research Laboratory of Chandigarh executed a very important project on structural integrity assessment of the 500 MW(e) FBR under core disruptive accident (CDA) conditions. This project consists of about 65 specialized explosive experiments, which were completed in a period of 4 years. The results from these projects were crucial for the safety clearance for construction, and also provided important inputs for FUSTIN code developed in-house for modeling CDA. Several important projects, for example, in support of leak-before-break (LBB) justification for the steam generator, have been executed in Structural Engineering Research Centre (SERC), Chennai. The structural integrity of Core Support Structure (CSS), including redundancy in stiffener design, has been verified by experiments on 10 models of 1/5th scale at Central Building Research Institute, Roorkee. Development of inflatable seals for small and large rotating plugs (SRP/LRP) of 500 MW(e) FBR is being carried out in collaboration with Defence Materials Stores R&D Establishment (DMSRDE), Kanpur, with active participation of academic institutes and Indian industry. A similar exercise is underway for the development of inflatable seals for inclined fuel transfer machine (IFTM) in collaboration with Hari Shankar Singhania Elastomer and Tyre Research Institute (HASTERI), Rajasthan. Development of a suitable process for plasma Teflon coating of the inflatable seal mating surfaces is being carried out in collaboration with Facilitation Centre for Industrial Plasma Technologies (FCIPT), and Institute of Plasma Research (IPR), Gandhi Nagar.

***..Apart from the contributions from eminent faculty members, the inputs provided by the dynamic and enthusiastic students have been commendable. Thus human resource development has been one of the areas of emphasis in the management philosophy of the Centre...***

Successful collaboration of IGCAR with Fluid Control Research Institute (FCRI), Palakkad, for the last fifteen years deserves a special mention. Each of the projects has provided important inputs with respect to flow patterns, and pressure distributions etc., helping in achieving desirable design for the sodium pumps, grid plate and Intermediate Heat Exchanger (IHX). The projects include fabrication & testing of non-return valve of primary sodium pump in water, 1/3 scale model of grid plate in air, secondary flow distribution in air for IHX, secondary outlet mixer for IHX, sleeve valve behaviour in water for IHX, and IHX/inner vessel mechanical seal in water. Currently fabrication and testing of 5/8 scale model of surge tank in water is in progress, with the objective of assessing the gas entrainment mechanisms. AU-FRG Institute of CAD/CAM - Anna University, specializes in modeling of very complex geometry such as valves, pump impellers / diffusers, and rotating parts, generating fluid mesh, and importing it into commercial computational fluid dynamics (CFD) package for flow and heat transfer simulations. Their expertise has been utilized in estimating the pressure loss coefficient of sodium service butterfly valve of a reference design, and comparing the predictions with water experiment results to arrive at optimal design for the valve. Similarly, their expertise has been effectively utilized to arrive at the optimal design for the discharge bowl of the secondary sodium pump that offers minimum pressure drop. Several projects have been carried out in collaboration with the research laboratory of M/S Kirloskar Brothers located at Kirloskarwadi, to develop the hydraulic design of primary and secondary sodium pumps for the 500 MW(e) FBR, to achieve the requisite head-flow characteristic and arrive at cavitation-free operation. Anna University is involved in projects on wireless communication of process signals, and Field-Programmable Gate Array (FPGA) based MIL-STD-1553 Bus interface.

Over the years, the mandate of the Metallurgy and Materials Programme has become comprehensively broad based, and this is reflected in the range of collaborative researches with the various institutes. Projects involving non-destructive evaluation (NDE) include: application of criticality refracted longitudinal ($L_{CR}$) ultrasonic waves for deformation and residual stress assessments in stainless steel plates and components of nuclear industry in collaboration with Anna University; design and fabrication of MEMS ultrasonic transducers for NDE applications, in collaboration respectively with IISc, Bangalore and Central Electronics Engineering Research Institute (CEERI), Pilani; and development of ultrasonic phased array based techniques for rapid evaluation of end plug welds in fuel pin assembly in collaboration with IIT Madras. Two other NDE projects in collaboration with IIT Madras may be mentioned here: transient infrared thermography based detection of blisters in pressure tubes of Pressurized Heavy Water Reactors (PHWR), and eddy current based time domain electromagnetic survey system for remote sensing of uranium deposits. IIT Madras and Defence Metallurgical Research Laboratories (DMRL) collaborated with IGCAR in development of ferromagnetic material with requisite Curie temperature for applications in safety rod drive mechanisms. Facilities in IISc, Bangalore have been extensively utilized for generating the base line data necessary for identifying the safe processing windows of important structural steels for FBR using Dynamic Material Modeling approach. IISc, Bangalore is also involved in a project on mitigation of bio-fouling of Ti surface in the coastal waters of Kalpakkam. A project to investigate fretting wear and tribological behaviour of Modified 9Cr-1Mo/Aluminised IN 718 Materials combination and SS 316 L(N), has been sponsored at IIT Delhi. Another project to investigate tribological behaviour of stainless steel 316 L(N), Colmonoy deposits on stainless steel 316 L(N), CrN coating on stainless steel 316LN and ASTM A453 Grade 660 has been sponsored at IISc, Bangalore. These projects will generate important base line data, and will also mark the beginning of a new area of research in IGCAR, namely correlation between microstructure - tribology and fretting properties. In recent years, it has been increasingly recognized that welding and hardfacing technologies are crucial to the success of our FBR and reprocessing programmmes. As a part of development of remote in-situ repair welding of 500 MW(e) FBR components, a project has been initiated with Indian Statistical Institute (ISI), Kolkata, and also BARC to develop computational intelligence-based remote welding system. A technologically important area in which IGCAR has developed expertise is dissimilar metal welding. A multi-pronged approach has been undertaken, to generate a research base, which will eventually lead to the identification of the technologically superior method. Accordingly, projects that have been initiated are on friction welding of Ti to 304L SS in collaboration with IIT Madras; diffusion bonding of Ti to 304 L SS in collaboration with PSG College of Technology, Coimbatore; and explosive welding of Ti to 304L SS in collaboration with Annamalai University. A BRNS project on optimization of Colomonoy deposition process is also in progress in collaboration with Annamalai University.

The collaboration between National Metallurgical Laboratory (NML), Jamshedpur and IGCAR is decades old - IGCAR has been steadily utilizing the excellent creep testing facilities in NML to generate long term creep data for FBR applications. This collaboration has been strengthened over the years; some of the recent projects are evaluation of creep, low cycle fatigue and creep-fatigue interaction on indigenous 316(N) welds and indigenous Mod 9Cr-1Mo base metal. Similarly, IGCAR has been an important partner of CSIR programs on Component Integrity Evaluation Programme, and its Millennium Programme on Predictive Technology Development for Engineering Components.

IGCAR is also an active participant in several other important BRNS sponsored projects. A first of its kind high temperature ultrasonic measurement facility has been established at MEPCO Schlenk Engineering College, Sivakasi. In addition to dynamic detection of phase and structural transitions in alloys and oxide systems, a technologically significant outcome of this project is the realisation that creep and/or fatigue damage can be detected with high sensitivity by measuring ultrasonic parameters at above ambient temperatures. IGCAR collaborated with IIT Madras in the BRNS sponsored project on welding procedure development and performance evaluation of a steam generator transition joint. The optimised trimetallic Grade 91/Alloy 800/ SS 316L(N) joint proved superior to the direct Grade 91/ SS 316L(N) joint for the extended service at elevated temperatures in the steam generators. Titanium based coatings on austenitic stainless steels by molten salt route for applications in severe corrosive nitric acid environments are being developed in collaboration with PSG College of Technology, Coimbatore. Through these endeavours, we have been able to provide support for enhancing the infrastructural facilities at the academic institutes, in addition to providing opportunities for the students to participate in areas of exciting science and challenging technologies.

IGCAR is also actively participating in several projects sponsored by the Department of Science and Technology (DST). A DST sponsored project has been initiated for setting up of a superconducting quantum interference device (SQUID) based magneto encephalography (MEG) system for non invasive studies of human brain in collaboration with National Institute of Mental Health and Neuro Sciences, Bangalore. Another important project of current international relevance, is Intelligent Processing of Materials (IPM) that involves on-line monitoring of the process parameters and necessary corrections for the production of defect free products. IPM is particularly important for nuclear and other strategic sectors for the fabrication of components with stringent quality requirements. IGCAR has played an active role in a DST sponsored IPM project involving academia, research institutes and relevant industries. A number of NDE procedures for on-line monitoring of welding processes have been successfully developed in the case of end plug welds, spacer pad welds and bearing pad welds, in fuel subassemblies of PHWRs, in collaboration with NFC. On-line detection of formation of defects and quantification of depth of penetration during welding has been successfully demonstrated using acoustic emission and thermography techniques. IGCAR played a key role in establishing the NDT Centre at NML, Jamshedpur with the support of DST, to meet the demands of petrochemical, railways and defence sectors. A number of NDE techniques have been established for finger printing of precious South Indian Bronzes for scientific recording of authentication, in collaboration with the Government Museum, Chennai. A few campaigns have been successfully undertaken to gain insight in to the fabrication technology employed and the reasons for the corrosion resistance of the famous Delhi Iron Pillar, and also to provide methods for its long term preservation. The technology for boriding of steels has been developed in collaboration with PSG College of Technology, Coimbatore. Synthesis and consolidation of oxide dispersion strengthened ferritic steels by powder metallurgical route is being pursued at the same institute. In collaboration with Technology Information Forecasting & Assessment Council (TIFAC) and Tamil Nadu Zari Ltd., IGCAR developed a XRF based system for non destructive assessment of the quality of the Zari (specifically the silver content) in the saris, which was a tremendous success in terms of cost effectiveness and wide public acceptance with high satisfaction.

The development of novel extractants and resins for reprocessing and waste management is a typical example of an area where there are strengths in academic and research groups that can complement those in DAE. The extractants and resins so developed can be tested for their performance with radioactive solutions by our personnel. This approach has been adopted in collaborating with National Chemical Laboratory (NCL), Pune, Thermax Limited, Pune, and IIT Madras. The interaction with NCL is expected to lead to commercially viable synthesis of extractants. Thermax Limited has already commercialized one of the resins developed jointly with IGCAR, and thus, bulk quantities required for experiments with actual radioactive solutions are now easily available. One of the ion exchange resins produced by Thermax Limited is also being tested for Pu purification at BARC as a step towards indigenisation of this vital material. Development of processes for bulk scale production of precursors for development of matrices for radioactive waste immobilization is another area where the involvement of organizations such as NCL Pune would lead to a holistic assessment of the synthesis procedures. Other challenging areas where the problems lend themselves to studies by outside groups include the development of new processes for boron carbide production, leaching behaviour of immobilized wastes etc. The development of chemical sensors is an important activity, the product of which would not only benefit the Department but also lead to industrial applications in a large way. The development of sensors is a multidisciplinary activity involving not only chemistry, but also electronics, instrumentation and precise fabrication. Our interactions with Central Glass and Ceramic Research Institute (CGCRI) and IIT Kharagpur are expected to catalyze this activity through the expertise available in these institutions in development of ceramics. Interaction with CSIR laboratories such as Central Scientific Instruments Organisation (CSIO), Chandigarh would also help us to take the products to commercial domain which would ultimately benefit the country immensely through the availability of indigenous and affordable products.

## Collaboration under the UGC-DAE Scheme

Collaborative research under the Inter-University Consortium - Department of Atomic Energy Facilities (IUC-DAEF) Scheme was initiated at Kalpakkam in 1994, with the purpose of enhancement of utilization of the accelerator facilities at IGCAR. Research scholars from various universities in India have made use of the low energy accelerators for pursuing research on ion beam modification of materials, and for characterization of materials using Rutherford Back Scattering, Particle-Induced X-ray Emission (PIXE) etc. In this scheme, 13 students have completed their Ph.D programmes, and it is satisfying to note that all of them are well placed in research laboratories both in India and abroad. With the recent enlargement of the scope of University Grants Commission-Department of Atomic Energy Consortium for Scientific Research (UGC-DAE-CSR) Scheme, to encompass facilities other than accelerators, it is expected that the collaborative ventures will grow in strength. Many talented students from different universities would benefit from this opportunity of working with state-of-art and advanced techniques, many of which are available only in a few selected laboratories in the Country. The impetus provided by these opportunities for young students to continue pursuing advanced research for their professional career is indeed heartening.

## Memoranda of Understanding (MoU) with Educational Institutes

To formalize the research linkages, IGCAR has signed Memoranda of Understanding (MoUs) with several Premier academic institutessuch asAnna University, IIT Madras, IISc Bangalore. These MoUs have provided opportunities not only for the research students and faculty from these institutes to interact with IGCAR scientists, but also provided opportunities to IGCAR scientists to participate in the educational process through seminars and joint discussions.

## Project Students at IGCAR

Every year nearly 200 undergraduate and postgraduate students are selected to participate in the various on-going projects at IGCAR, encompassing various facets of materials development, chemistry, reprocessing, reactor design and safety. These opportunities are aimed at motivating the young minds and to groom them to become competent professionals. The benefits derived from such interactions are quicker R&D outputs, from eager and sharp, if not fully matured students, not to mention the expertise of the Institute guide. The DAE Graduate Fellowship Scheme (DGFS) recently started by DAE, is similar in spirit to identify talented students immediately after their undergraduate degree and nurturing them to contribute to Departmental mission programmes, by sponsoring their postgraduate study and enrolling them as employees of the Department. The benefits to IGCAR from this scheme have already been tangible both in terms of enhanced DAE-IIT linkage and quality of human resource addition. The CSIR and DST scholarships and the various Junior Research Fellowships (JRF) programmes including DAE-JRF, K.S. Krishnan research associateship etc., facilitate qualified young graduates and postgraduates to execute projects at IGCAR. This has also served the purpose of accelerating the designated programs while contributing to the human resource development of the country.

## SummerTraining Programmes in Basic Sciences

IGCAR has been conducting six week long annual Summer Training Programme for M.Sc (I Year) students in Physics and Chemistry, called STIP and STIC respectively. Starting from 1995, every year, 20 students are selected, in each discipline, from more than 200 applications. The students receive stipend during their stay. Initially, this programme was confined to students from Tamil Nadu and Pondicherry. However, in view of the overwhelming response, this programme has been extended to an all-India basis from 2005. In this very popular programme, running during May-July every year, the selected students undergo an intensive training comprising of lectures, project work and tutorials. Many of the students who had attended these courses went on to pursue research careers at prestigious universities, and some of them also joined DAE through the BARC training school. These courses have also created a fraternity of students, who have helped to create an awareness of the R&D activities of the Department amongst the colleges and universities. IGCAR is associated with Chennai Mathematical Institute (CMI) in the conduct of the experimental programme for B.Sc. (Hons.) physics students. IGCAR scientists are also involved in giving lecture courses to the students at CMI. IGCAR has also been involved in the conduct of an Indian Academy of Sciences sponsored refresher course for college teachers. A DST sponsored Science & Engineering Research Council (SERC) School on

Methods in Materials Characterisation for research scholars was organized at IGCAR in February 2004.

## IGCAR Expertise to Strategic Sectors

IGCAR is extending its expertise in formulating the facilities and activities in the areas of damage tolerant design, damage mechanics and NDE based damage evaluation for Kaveri engine of the light combat aircraft. The oxygen sensors with associated electronics developed by IGCAR, for deployment in the cock-pit of the light combat aircraft to warn the pilot in case of a fall in the oxygen level, have been successfully retrofitted to the existing oxygen management systems. IGCAR has extended its expertise and facilities for integrity assessment of rocket motor by employing acoustic emission monitoring during hydro testing. IGCAR has also provided expertise and facilities for integrity assessment of rocket motor casings, satellite tanks etc. by employing advanced NDE techniques and procedures. Fitness for purpose based evaluation with engineering judgment helped in preventing delays in mission programmes. IGCAR is extending the KAMINI based neutron radiography facility for rigorous quality evaluation of critical pyro-devices used in the launch vehicles and satellites. IGCAR has extended its expertise and facilities for development of NDE procedures for life assessment and extension of fighter aircrafts and helicopters, thus saving crores of rupees of precious foreign exchange. The core expertise and unique facilities at IGCAR have thus significantly contributed to the success of several programmes of strategic sectors, by aiding early realization of indigenous technologies. The contributions of IGCAR to the National mission, thus go beyond its primary mandate of developing fast reactor technology.

## International Research Collaborations

Given the mandate of IGCAR, and also its formidable expertise in some associated areas, it is inevitable that there has been a gradual increase in the number of International interactions and collaborations. In deed, in several cases, the proposals for collaboration have originated from the foreign laboratories, a testimony to the overwhelming and clear strength of IGCAR in the relevant areas.

The early collaboration of IGCAR with the French Atomic Energy Commission (CEA) dates back to 1969, when the Fast Breeder Test Reactor (FBTR) was conceived to be built by adaptation from theFrench fast reactor Rapsodie, with several design modifications. Towards this, a MoU was signed between DAE and French CEA for (a)transfer of design and drawings of Rapsodie fast reactor, (b) training of Indian team in design and operation, and (c) transfer of manufacturing technology of critical components. A number of scientists and engineers from IGCAR visited France (1969-1974) towards strengthening their expertise in design, operation and maintenance of FBRs. IGCAR reestablished collaboration with the French Atomic Energy Commission (CEA) in 1989 to exchange computer codes in the field of thermal hydraulics and structural mechanics. Under this collaboration, from CEA, IGCAR received CASTEM 2000, PLEXUS and TEDEL codes for structural mechanics analysis. Recently, DAE has established collaboration with CEA in wider spectrum of areas related to safety of fast reactors and radiation damage.

***These interactions promote inter-laboratory co-operation and cross-fertilization of ideas, and benefit the programmes of both the IGCAR and the concerned foreign institution. ...***

IGCAR has been an active participant in the International Working Group on Fast Reactors, and other International Atomic Energy Agency (IAEA) activities of interest to FBR programmes. IGCAR hosted during 13-17 January 2003, the IAEA Technical Meeting on "Primary Coolant Pipe Rupture Event in Liquid Metal Cooled Fast Reactors", in which international experts from several interested member countries participated. IGCAR has also been actively participating in international cooperative research programmes of IAEA in the areas of reactor engineering, reprocessing, and safety. IGCAR has actively participated along with France, Japan, Korea and Russia on the investigation of thermal striping damage of the expansion tank of Phoenix reactor. The thermal hydraulic as well as structural damage predictions made by IGCAR scientists matched very well with plant data. In another cooperative research programmme in which IGCAR contribution has been greatly appreciated relates to intercomparison of computer codes to predict seismic behaviour of liquid metal fast breeder reactor cores. In the cooperative research programmes on core mechanics of FBRs, the predictions by IGCAR scientists were found to be in good agreement with the experimental observations. IGCAR is actively participating in several current cooperative research programmes of IAEA. One example in the area of reactor physics is on updated codes and methods to reduce calculated uncertainties in reactivity coefficients in liquid metal fast breeder reactors; China, France, Japan, Korea, Russia and USA are collaborating in this project. IGCAR is also participating in collaborative research studies of advanced reactor technology options for effective incineration of radioactive waste. An example in the area of reprocessing is on the separation efficiencies for La, Ce and Nd in the oxide electro-winning process using $MgCl_2$ based electrolyte, in collaboration with China, Czech Republic, Japan, Korea and Russia. IAEA has initiated an International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) with a view to ensuring sustainable nuclear energy towards fulfilling energy needs for the twenty-first century. India is a member of this project. As part of this project, IGCAR is actively participating in a joint case study on assessment, using the INPRO Methodology, for an Innovative Nuclear Energy System based on a Closed Nuclear Fuel Cycle with Fast Reactors (CNFC-FR). The objectives are to assess the long term viability of technology options and innovations, and identify areas where research and development is required. The participating countries are China, France, India, Korea and Russia, and Japan as observer. IGCAR is an active member in the Technical Working Groups on nuclear fuel cycle options and nuclear data evaluation, and Standing Advisory Group on nuclear energy.

As a part of the protocol between DAE and - l'Organisation Européenne pour la Recherche Nucléaire (CERN), Geneva, so far five scientists have been deputed from IGCAR to CERN, each for a period of 1 year, for carrying out testing and evaluation of the 1200 huge super-conducting di-pole magnets for the Large Hadron Collider (LHC); this is a giant underground accelerator designed for accelerating protons to 14 TeV and lead nuclei to 1150 TeV for basic studies in particle physics, the next major project of CERN.

IGCAR has also been actively participating in the collaborative research programmes with the premier R&D institutes in Germany under the aegis of Indo-German Bilateral Agreement. In the early years, the areas of collaboration included sodium chemistry, high temperature mass spectrometry, high temperature calorimetry, and solid state physics including radiation damage and low temperature physics. Subsequently, the range of collaboration has considerably expanded to include many other front line areas of common research interest in science and technology, including vibration noise monitoring and analysis for diagnostic purposes in nuclear power plants, and micro-meteorological studies using Sonic Detection And Ranging (SODAR) system for prediction of dispersal of radionuclides. These projects also fostered close collaboration between Indian and German scientists, including mutual visits. The experience and expertise thus generated have been valuable not only to IGCAR, but also to the host institutions in Germany. An important area of direct interest is that of high temperature mechanical properties, namely, creep, fatigue and their interaction, and also fatigue and creep-fatigue crack growth behavior in liquid sodium. These studies have richly contributed to the basic understanding of such properties and benefited fast reactor design. Over the years several projects have focussed on high temperature components: creep-fatigue interactions and fracture mechanics properties and their correlation for high temperature materials, including steels and their weldments, and also Ni-base superalloys; methodology for high temperature component life assessment; and monitoring & repair welding of high temperature components. The results from these studies have clarified many basic issues, and enhanced capability in life prediction of engineering components. An extensive project addressed the issue ofenvironmental degradation of stainless steels and their welds and the effect of nitrogen content thereon, and corrosion properties of spun-melt ribbon and bulk metallic glasses of Zr-based systems with superior corrosion resistance. Another such extensive study has been on the science of oxidation of high temperature materials, a topic of perennial interest to power plants. Indo-German Collaborative Programme on NDE is an extensive collaboration that charted several new paths - including development of ultrasonic and micromagnetic techniques with innovative approaches for characterization of microstructures and deformation process, and development of eddy current impedance imaging for quantitative characterization of defects and also knowledge based systems for NDE applications. Two IGCAR scientists obtained their doctoral degrees from a German University based on the investigations carried out under this programme. This interaction has considerably enhanced IGCAR impact and recognition as one of the premier NDE research Centres in the international NDE community, and is a fine example of the importance and impact of such collaborations with premier international institutions.

In an Indo-French Collaborative Programme on Ferrofluids, a device has been developed that can measure forces of the order of $10^{-13}$ N between colloidal particles, and it has been effectively utilized for characterizing ferrofluids and their emulsions with long term stability. The programme has led to filing of four patents that include force apparatus, ferrofluid based magnetic flux leakage measurements for non destructive examination and optical filters. The technology is now being adapted to develop dynamic seals for sodium pumps used in fast reactors. In collaboration with Centre for NDE, Iowa State University, a three dimensional boundary element model has been developed and validated for detection and quantitative evaluation of surface and subsurface cracks in structural components. In collaboration with Michigan State University, East Lansing, modelling of response of SQUID sensors developed in IGCAR for detection of defects through flux leakage measurements has been taken up for optimization of the sensor design.

IGCAR is a partner in some of the international collaborative projects under the aegis of Department of Science and Technology. An ambitious DST-DAAD collaborative project is aiming at comprehensive understanding and quantitative characterization of thermomechanical fatigue in power plant materials, and IGCAR and Universität Siegen, Germany, have been identified as the principal partners. Under this project, so far 4 Indian scientists have visited Germany and 4 German scientists have visited India. University of Science and Technology, Beijing and IGCAR are collaborating on a project on remnant creep life prediction model for power plant components. Another project is on yield criterion for superplastic metals and alloys, with Moscow State University, University of Hyderabad, and IGCAR as the collaborators; recently a Russian scientist has visited IGCAR for carrying out experimental work under the auspices of this project.

The contribution to expertise pool of IGCAR from personal initiatives deserves a mention here. A few of our scientists havebeen been awarded the prestigious Alexander von Humboldt Fellowship, which gave them the opportunity to work in premier laboratories in Germany. Many of our scientists have spent between one to two years as Post-Doctoral fellows, or shorter periods, in many leading laboratories in Japan, USA, Europe, and Australia. The areas of research for such visits have invariably been in the frontiers of current or near-future interest to IGCAR. Similarly, several scientists from foreign laboratories have visited IGCAR for periods ranging up to 1 year, to work on projects of common interest. International interactions promote inter-laboratory co-operation and cross-fertilization of ideas, and benefit the programmes of both the IGCAR and the concerned foreign institution

## Networking with Industry

In tune with the philosophy of DAE, IGCAR since its inception has pursued rigorous and keen interactions with capable industries, towards mastering high technology and maximizing indigenisation. The total indigenous content of FBTR was more than 80%, considered quite high in the light of the maturity of Indian industries in 1970s & 80s. This philosophy of self reliance underlines IGCAR approach to design and construction of 500 MW(e) FBR as well.

The burn-up of the fuel sub-assembly is limited by the in-reactor performance of the core structural materials. Since high burn up is essential for economic operation of FBRs, IGCAR took up the challenging task of indigenous development of the candidate material for clad and wrapper of FBRs, a 15Cr-15Ni-2.3Mo-Ti modified austenitic stainless steel (alloy D9). Technology developed through in-house R & D for optimizing the melting, casting, forging and heat treatment conditions was adapted by Mishra Dhatu Nigam (MIDHANI) for commercial production. Using the ingots from MIDHANI, clad and wrapper tubes were successfully produced at NFC. Whereas alloy D9 will be used for the initial core of the 500 MW(e) FBR, efforts are underway to develop modified grades of alloy D9 called D9I for clad and wrapper tubes for increased burn up. A number of heats of this improved grade D9I are now produced at MIDHANI. Efforts are also now underway, in collaboration with MIDHANI, for the development of ferritic-martensitic grade steels (P91) for use as wrapper material in future cores of FBRs.

The major structural materials required for 500 MW(e) FBR project are stainless steels type 304L(N), 316L(N), A48P2 ferritic steel, and modified 9Cr-1Mo steel for steam generator. A programme to indigenously develop all materials required for 500 MW(e) FBR has been successfully concluded by networking expertise and facilities in the industry with R&D inputs from IGCAR. Also, the steel plates are to be produced in large sizes, to minimize the number of weld joints in the components - the weakest link in high temperature structures. In collaboration with IGCAR, Steel Authority of India Limited (SAIL) successfully rose to the challenge of producing these steels within the narrow specification ranges and with very low inclusion contents, in large thickness and sizes required, for the first time in the country. For this purpose, SAIL pooled its resources, with steels being melted in the Alloy Steel Plant (ASP), Durgapur, and then rolled into plates in the Rourkela Steel plant (RSP), another SAIL unit. Also, vendors were developed to carry out edge cutting, pickling and passivation of stainless steel plates. As a result, it is now to possible to produce all plates of 304L(N), 316L(N) and modified 9Cr-1Mo steel in required sizes, within the country. The mechanical properties of these indigenously produced materials compare favourably with those of the imported materials. Based on R&D efforts in IGCAR, optimum forming conditions were also identified and implemented in the industry to process various products like plates, tubes and forgings of various steels. This success has generated full confidence that the major materials for FBR construction can be produced within the country at a competitive cost. Another collaboration between IGCAR, MIDHANI and NFC has led to success in manufacturing 23 meters long tubes of modified 9Cr-1Mo steel for the FBR steam generator. The modified 9Cr-1Mo steel was produced by electroslag refining process at MIDHANI to the required chemical composition and inclusion control, and the forged rounds were then converted into long seamless tubes at NFC.

***As a result it is now possible to produce all plates in sizes required for 304L(N), 316L(N) and modified 9Cr-1Mo steel within the country. The mechanical properties of these indigenously produced materials compare favourably with those of the imported material***

IGCAR successfully collaborated with M/s Mailam India Ltd., Pondicherry and MIDHANI in indigenous development of basic-flux coated modified E316-15 (optimised 18Cr-12Ni-2Mo) austenitic stainless steel electrodes, and non-synthetic Grade 91 welding electrodes (conforming to AWS classification E9016-B9 of ASME section II-C SFA-5.5) for shielded metal arc welding, as per 500 MW(e) FBR specifications. IGCAR carried out the chemical analyses and mechanical tests, and provided research-based inputs on flux composition considering slag detachability and optimal weld metal composition for achieving the mechanical property requirements. It may be noted that the indigenously produced welding consumables compare favorably with those available in the international market, both in the properties, and in price.

The construction of a 500 MW(e) FBR requires fabrication of several large and intricate components. Also, it is necessary to adopt state-of-the-art technology in manufacturing and inspection to ensure a design life of forty years and beyond. Therefore, it was considered prudent to undertake systematic manufacturing technology development for all the major components, in collaboration with selected Indian manufacturers with proven track records. Many test and developmental subassemblies have been fabricated, and hydraulic experiments and testing of the fuel handling equipment have been carried out. Other components for which technology development have been carried out include steam generator (SG), main vessel, control rod drive mechanisms, roof slab, grid plate, transfer arm, failed fuel location module, and sodium pumps. A few examples of collaborative development with industry are mentioned below:

The manufacture technology for steam generator was taken up with M/s. Larson and Toubro and M/s. Bharat Heavy Engineering Limited (BHEL), Thiruchirapally. This involved several developmental activities: design of the tube to tube sheet joint, bending of tubes, end machining, forming of shell pullout, establishment of tube to tube sheet weld repair and plugging technique, and post weld heat treatment of entire component. To obtain the acceptable quality of tube to tube sheet welds, a number of weld trials were carried out before qualifying the welding procedure. Towards this end, the support of in-house R&D of IGCAR was used to establish various procedures, by conducting several weld trials and characterizing using NDT.

The manufacturing technology for roof slab (RS) is established through M/s Larsen and Toubro. This is a large box type annular structure made from A48P2 carbon steel material with controlled chemistry and required mechanical properties, and complex geometry. The manufacture of RS involves the following important operations: Rolling and welding of shells to close profile tolerances of 0.2% on radii; Post weld heat treatment of the thick flanges; Controlling distortion on carbon steel/ stainless steel/ dissimilar metal welds to achieve close tolerances. One critical consideration in the manufacture of this component is the strict control of distortion during welding. 75° full size sector (weight 40t) was chosen for developing manufacturing technology. Shop and site manufacturing features have been adopted in the manufacture of the above sector.

For FBTR, grid plate was the only major component that had to be imported from France in 1976 due to the critical technology involved in its manufacture. Success in the development of technology for the grid plate of 500 MW(e) FBR by fruitful collaboration between IGCAR, M/s. MTAR, Hyderabad and M/s. OMPLAS, Chennai demonstrates the growth in technological competence of the Indian industry to meet the technological challenges of Indian nuclear power programme. With this development of indigenous capability for manufacture of grid plate, another milestone has been achieved in the country's nuclear power programme.

The technology development for the manufacture of the main vessel (MV) consisted of manufacturing a 45° sector covering all the important aspects of the MV. The MV is a 13 m diameter and 13 m height pressure vessel made from type 316 L(N) austenitic stainless steel. The manufacturing requirements were design of the dies for pressing petals to close dimensional tolerances, SS weld overlay, special techniques for accurate measurement of the profiles, helium leak testing of welds using vacuum jacket method and on-site fabrication due to transportation limitations. The finite element simulation of the forming process carried out at IGCAR has given critical inputs for the design of the die profiles for near net shape forming of petals. The experience gained during technology development with M/s. BHEL, Thiruchirapally has given enough confidence that the manufacturer is certain of achieving the manufacturing requirements and meeting the delivery schedule also.

The manufacturing technology for pump components such as shaft, impeller, hydraulic bearings etc. has been developed indigenously. All the sub-components such as long shaft have been tested for performance. Experience in manufacturing technology development manufacturing components for 500 MW(e) FBR. Another major effort was towards designing and manufacturing of primary sodium pumps, which circulate the sodium at 670K through the reactor core thereby extracting the nuclear heat generated in the core.

The control and safety rod drive mechanism (CSRDM, 9 numbers) and diverse safety rod drive mechanism (DSRDM, 3 numbers) are independent fast acting mechanisms for reactor power control and safety. Specifically, these mechanisms should be able to scram the reactor within 1 second, if required. These mechanisms along with the respective absorber rods operate in fail-safe mode. Extremely high reliability is to be ensured for CSRDM and DSRDM. Height of each mechanism is about 11 m, and maximum diameter is about 350 mm. Each mechanism comprises about one thousand precision machined (within stringent tolerances) and proprietary items. Full scale prototype CSRDM and DSRDM were manufactured by M/s MTAR, Hyderabad, based on detailed design drawings prepared by IGCAR. The prototypes were then thoroughly tested at manufacturer's shop for all the functional aspects of the mechanisms; the tests results were much better than specified.

***..It can be justly claimed that in this manner, DAE has ushered in new levels of manufacturing standards in the industry...***

## Concluding Remarks

Outsourcing of R&D through collaborations with academic institutes has helped IGCAR in many ways. Critical inputs have been generated in relatively short period, which have helped in early launching of the 500 MW(e) FBR program. In the process, infrastructure has been developed at many Centres of excellence.

IGCAR has also significantly contributed to the development of science and technology education, both directly and through the academic institutions. Intense collaborations with competent industries in the course of technology development exercises have paved the way for incorporating up-to-date manufacturing and inspection technologies for 500 MW(e) FBR fabrication. The partnering industries have also matured in the technologies for the manufacture of large and precision engineered components conforming to unprecedented levels of quality. It can be justly claimed that in this manner, DAE has ushered in new levels of manufacturing standards in the industry.

It is by harnessing the available multi-disciplinary expertise in the country covering the entire gamut from education and research to high-tech manufacturing, a level of technical achievement has been possible, which would be too difficult, if not impossible, to achieve for any single institution because of limitations of resources. The benefits from the close IGCAR- academia-research-industry interactions go substantially beyond nuclear energy, and have a much wider dimension of societal relevance. Given the mandate of our Centre, such collaborations between IGCAR and other premier institutes and industries will continue to be strengthened in the years to come.

DR. BALDEV RAJ
DIRECTOR

# Milestone in Reprocessing achieved: Reprocessing of 100 GWd/t burn-up Carbide fuel

Mixed carbide fuel of FBTR with 100 GWd/t burn-up has been successfully reprocessed in Lead Mini Cell (LMC). This is the highest burn-up fuel reprocessed so far in our country.

LMC is a compact shielded facility, with single pin chopper, electrolytic dissolver, feed clarification centrifuge and centrifugal extractors, which has been designed and developed to demonstrate reprocessing of the fast reactor fuel with mixed carbide. All the equipments are located in an α-tight containment box designed for remote operation and maintenance using devices like master slave manipulators (MSM), in-cell crane, sampling system and analytical equipment etc. A view of the facility as seen from inside the containment box is shown in figure 1. This facility was commissioned during the end of 2003. Progressive clearances by Safety Review Committee for Operating Plants (SARCOP) were obtained for the reprocessing the spent fuels with increasing burn-ups starting from low burn-up to 25, 50 and 100 GWd/t. The clearances were given based on the operating experience of the earlier campaigns. This procedure was adopted since reprocessing experience with this type of fuel and burn-ups is not available anywhere in the world.

## Fuel handling

The irradiated fuel subassemblies were discharged from FBTR and disassembled in the post-irradiation examination cells into individual pins. The disassembled pins were loaded in magazines. One magazine with 10 pins was transported at a time in a special α-tight container inside a lead shielded cask to LMC. This transfer of magazine into the cell is shown in fig. 2.

## Chopping

The pins were chopped in the indigenously developed single pin chopper (fig 3). Purging with dry argon gas is done to avoid flashes, which occur due to the pyrophoric nature of carbide fuels. The argon flow rate was optimized during the campaigns with low burn-up fuel pins. It was observed that the pyrophoricity seems to change only moderately with burn up and the argon flow requirement had remained same irrespective of the burn-ups.

## Dissolution

An important design input that is required from the LMC operation is that of the dissolution process. Based on the laboratory experiments on single pellet, the parameters were fixed in the plant for electrolytic dissolver operation. Electrolytic process was adopted to enhance the dissolution as

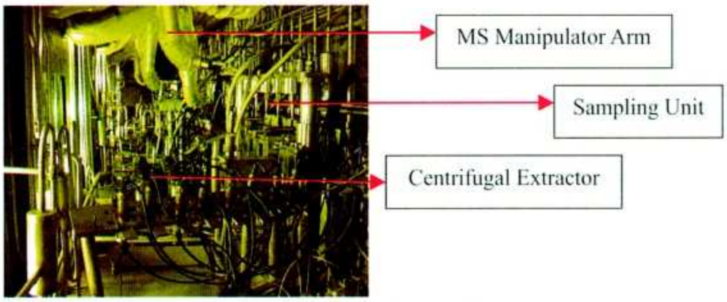



Fig.1 Inside view of LMC, showing intricate piping and paneling.

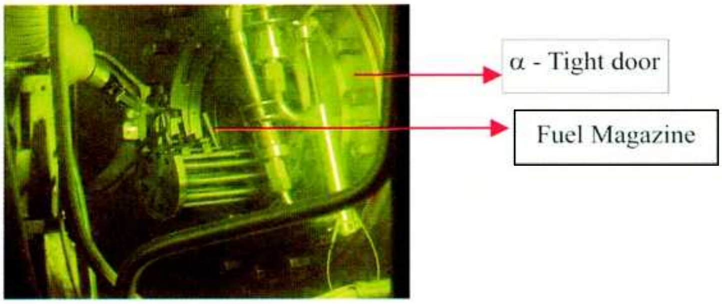



Fig.2 Carbide fuel pins being received in LMC


Fig. 3 Technological innovation - Indigenously developed Single Pin Chopper

well as to destroy the carbon compounds formed during the dissolution. The dissolution parameters were optimised during the campaigns. The difficulties in conditoning the dissolver solution also had been successfully overcome.

Hull monitoring was done with high purity germanium (HPGe) detector and the loss of SNM in the hulls was below 0.5%. A typical gamma spectrum is shown in fig 4.

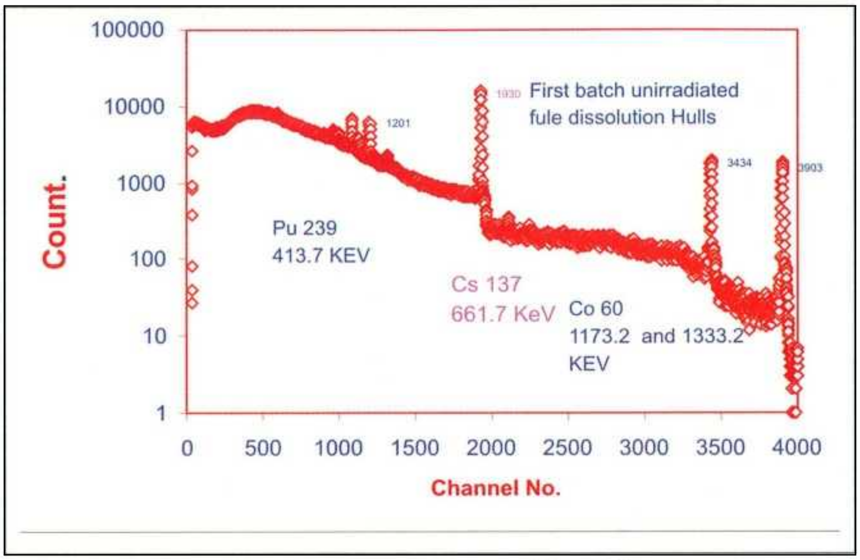



Fig. 4 Gamma ray spectrum of the Hull

## Feed clarification

The dissolver solution is clarified using the centrifuge operated with air motor. The centrifuge was inspected after the 25 GWd/t campaign. The performance of the unit is very satisfactory.

## Solvent extraction

To establish the extraction parameters in the plant, batch extraction and stripping runs were conducted in laboratory with the dissolver solution samples after dissolution. With the above studies, vital decisions as to whether any conditioning treatment is required or not could be taken for the destruction of dissolved carbon. The raffinate Pu losses in all the campaigns were within acceptable values. In order to reduce the Pu concentration in the lean organic, U(IV) nitrate stream was introduced in the strip section. By this, the Pu retention in lean organic was reduced.

The performance of centrifugal extractors was very good. The mixer volume in the first cycle of the centrifugal extractor was reduced by suitable design modification to increase the mixing efficiency, thereby reducing the raffinate losses. In another type of centrifugal extractor in LMC, which was of variable interface type, the sealing was modified to reduce the maintenance problem. Whenever there was a requirement to change the motor, it was done remotely with the manipulators and in-cell crane. The performance of the electrolytic mixer settler was satisfactory, but got deteriorated due to electrode degradation. Hence, direct precipitation cum partitioning through oxalate process was adopted. The results were very satisfactory.

## Reconversion

The operation in U & Pu reconversion facility was quite smooth and incident free and had given enough confidence to handle appreciable quantities and concentrations of Pu.

## Solvent treatment

Since the Pu retention was unacceptabily high, a new ammonium carbonate based process was proposed and adopted for plant operation. The results were quite satisfactory. The Pu was recovered and the solvent could be discharged for disposal.

## Hot cell operation and Maintenance

All the equipment such as MSMs, in-cell crane, sampling systems, capping-decapping systems and in-cell analytical systems had performed as per the technical requirements and found to be satisfactory. In-cell crane was maintained once. Improvement in the pneumatic conveying system had been carried out. Sample bottle design and conveying method had been modified based on the operational feedbacks.

## Instrumentation system

All the instrumentation systems for the measurement and data acquisition of process parameters; logic control systems in chopper, dissolver, centrifuge, centrifugal extractors; interlock systems for liquid transfer, sampling and exhaust & off-gas systems performed as per design specifications. The working of all the radiation monitoring instruments and fire alarm systems were satisfactory, as per the technical specifications. The spectrophotometry based system for direct measurement of Pu, performed very satisfactorily. This systems enabled easy process control of valency conditioning of Pu.

## Conclusions

The results of the campaigns so far have been extremely encouraging. They have given valuable inputs to undertake the design of chopper, dissolver and centrifugal extractors for the Demonstration Fast Reactor Fuel Reprocessing Plant (DFRP). Excellent experience has been gained in the remote operation and maintenance of hot cell equipment using in-cell gadgets. There were no air activity problems.

The successful reprocessing of 100 GWd/t burn-up short cooled fuel has provided valuable data as well as rich experience for fine tuning not only the process parameters but also the designs of vital process equipment for DFRP.

*(Dr. Baldev Raj, R. Natarajan, M. Venkataraman, A. Ravisankar, V. Sundararaman, M.S. Elangovan, V. Vijayakumar, P. Ramkumar, R.V. Subbarao, B.A. Anandarao Reprocessing Group)*

# An unique facility for void swelling simulation studies: Initial Results on D9 alloy

Radiation induced dimensional changes of the core components like fuel cladding and wrapper of a fast reactor due to void swelling and irradiation creep limits the long residence time needed for achieving high fuel burn-up. In 500MWe FBR, the clad and wrapper tubes will experience temperature in the range of 400°C-600°C under steady state condition and the maximum neutron dose for burn up of 100 GWd/t is 85 dpa. D9 Alloy (Ti-modified Ni-15.12%, Cr-13.95% steel), which is chosen as the material for the present core of FBR, has better swelling resistance as compared to SS 316 and is expected to have a target burn up of 100 GWd/t. At Materials Science Division(MSD), a programme on charged particle simulation of radiation damage behavior of reactor materials has been initiated. One of the important activities envisaged is connected with the development of D9I alloy with a target burn up of 150 GWd/t.

The ideal method of investigating radiation damage effects relevant to in-service condition is of course, the irradiation of the material in a test reactor under identical conditions. However, obtaining high damage of 100 dpa corresponding to a fast neutron fluence of $10^{23}$ n/cm$^2$ requires very long irradiation times up to a few years in a high flux test reactor. Irradiation of materials with energetic ion beams can bring down the irradiation time to several hours for achieving the same dpa. Damage rates attainable with different bombarding particles are shown for comparison in Fig. 1. As seen in the figure, damage rate created by heavy ions like Ni is several orders of magnitude higher than that by neutrons and hence Ni ion bombardment can yield very fast data under controlled conditions of temperature, flux and irradiation environment. We have undertaken the study of void swelling in D9 alloy using 5 MeV Ni ions from the 1.7 MV Tandetron accelerator following ASTM E-521-89 which summarises the standard procedure for ion simulation of neutron damage. Due to the large difference in the defect production rate, the peak swelling temperature during ion irradiation is higher than that for neutron irradiation. Since the earlier studies have shown that void swelling behaviour obtained from ion and reactor irradiation are similar at their respective peak swelling temperature, we have made swelling measurement as a function of temperature in order to find out the peak swelling temperature under ion irradiation.

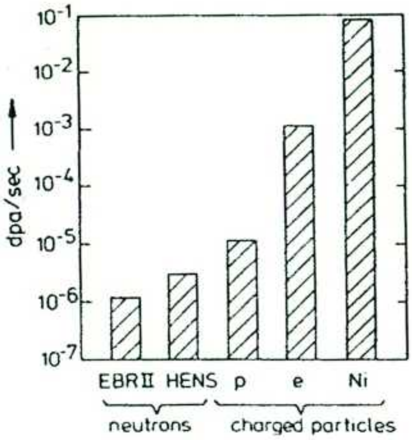



Fig. 1 Typical Damage rates attainable with different bombarding particles.

In order to establish and standardize the procedures the initial studies were carried out on D9 alloys obtained from M/s. Valinox, France. A setup for carrying out high temperature irradiations was designed and fabricated. Elimination of leakage currents which arise when sample is

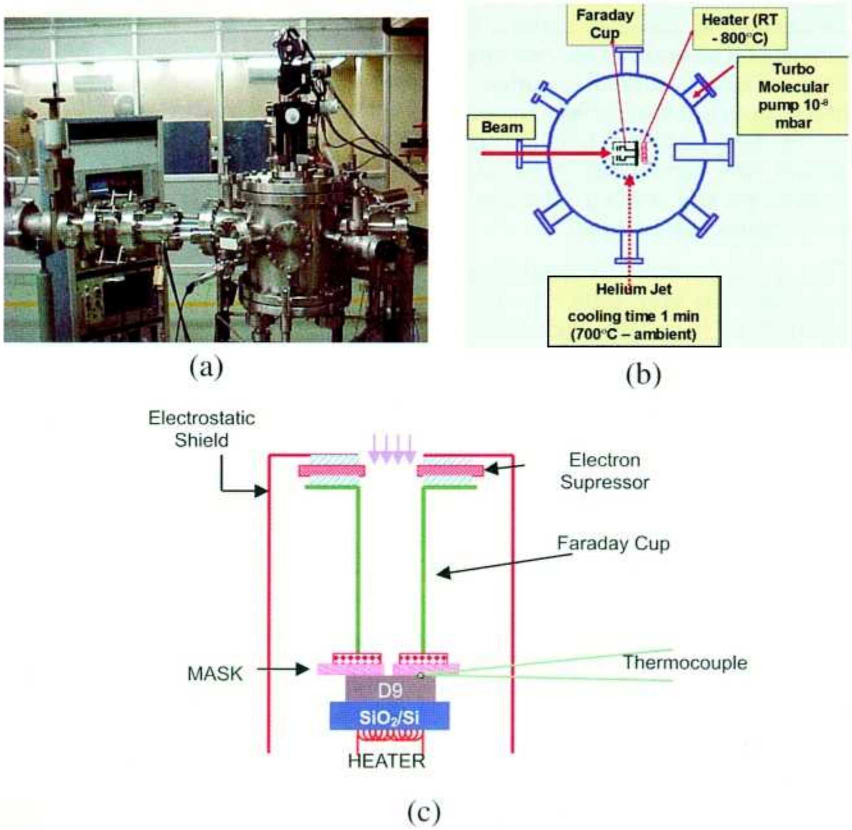



Fig. 2. (a) Photograph of the irradiation chamber. The Schematic of (b) the chamber and (c) the high temperature sample holder developed for irradiation studies

heated to high temperature is essential for the accurate measurement of irradiation dose. For measuring the beam current accurately a Faraday cup was provided on the sample. A bias of –300 V was used to prevent the escape of secondary electrons from the free end of the Faraday cup. An electrostatic shield was provided all around the target holder, for reducing the leakage current. Facility for quenching the sample to room temperature, after irradiation also has been incorporated in the irradiation chamber. A photograph of the ion irradiation setup, at the 10-degree beam line of the accelerator is given in Fig. 2 along with the schematic of the UHV irradiation chamber and the sample holder.

The samples were made into desired size by spark cutting from 18 % cold worked D9 alloy stainless steel. The samples were mechanically polished with a good surface finish. The average roughness of polished samples was ± 100 Å.The samples were preimplanted with 30 ppm of helium to simulate the production of helium in reactor structural materials by (n,α) reactions. Uniform Helium injection in the irradiated region was obtained by using multiple energy helium ion implantation using the 1.7 MV Tandetron accelerator. Figure 3 shows the helium and damage profiles calculated using Monte-Carlo simulation code TRIM. Subsequently, the samples were irradiated with 5 MeV Nickel ions at elevated temperature. The irradiations were carried out at different temperatures in the range of 400°C – 700°C. A temperature stability of ± 2°C was maintained using a temperature controller. Damage rate employed during irradiation was 7 x $10^{-3}$ dpa/s and the irradiations were carried out to a cumulative dose of 100 dpa. The beam was scanned over the sample surface in order to achieve beam homogeneity across the sample surface.

During ion bombardment, the specimen was masked so that part of the sample was irradiated while the other region was protected from beam. As the irradiated region swells, the surface becomes elevated and a step forms at the boundary of the masked and bombarded regions. A measurement of the step height provides the total integrated swelling that has occurred along the path of the bombarding ion. The step height was measured using a surface profilometer. The height h of the plateau raised from the initial surface could be given by a rough estimation

$$h = \frac{S_A}{1+S_A}\Delta R$$

where h = Step height, ΔR = Visible void spreading width and $S_A$ = The average void swelling in ΔR. ΔR was assumed to be $R_p + \Delta R_p/2$ where $R_p$ is the projected range of Ni ions and $\Delta R_p$ is the straggling.

The void swelling in D9 alloy as a function of irradiation temperature obtained using step height measurements is given in Fig.4 The peak swelling temperature during ion irradiation is 550°C. Normalizing for the temperature shift arising from the difference in the damage rate, peak swelling temperature is estimated to be 435 °C for n-irradiated D9 alloy

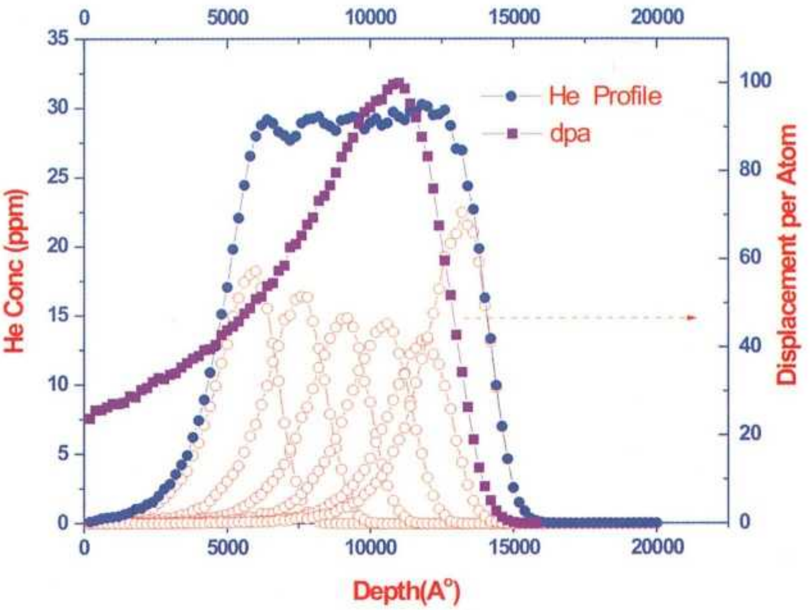



Fig. 3. Depth distribution of damage production and helium injection

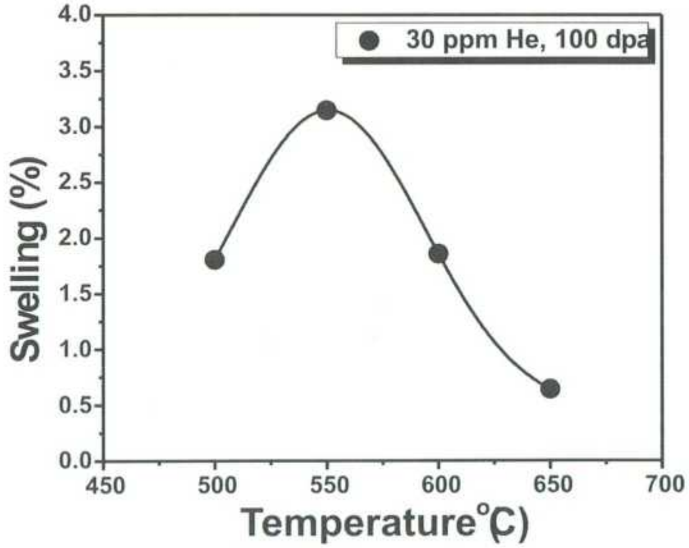



Fig. 4. The void swelling in D9 alloy as a function of irradiation temperature obtained using step height measurements.

which is close to JPCA alloy irradiated to 70dpa in FFTF. The magnitude of swelling at peak swelling temperature is 3.25% as compared to 10% observed for CW-316SS.

These unique experimental facilities for ion simulation of radiation damage have been setup for the first time in DAE at MSD, IGCAR. Initial studies, using the setup have clearly demonstrated the feasibility of utilizing heavy ion irradiation for simulating the displacement damage which occurs in fast reactor structural materials. The high dpa rate available during ion simulation facilitates the rapid screening of materials and can be effectively exploited for the development of alloys which are resistant to radiation damage. Currently, the screening of indigenously made D9I steel has been taken up as the next phase of studies

(Reported by Dr. K. G. M. Nair and Dr. B. K. Panigrahi, Materials Science Division)

# Technology for Enrichment of Boron – A Target Realized

Boron carbide enriched in $^{10}B$ to 65% is required for control rods of PFBR. A Boron Enrichment Plant (BEP) has been designed and commissioned in April 2001 (Ref: IGC Newsletter Vol 48, April 2001, pp 3-5). Figure 1 shows one of the views of the Boron Enrichment Plant. After commissioning, boric acid was charged to process ion exchange columns. The displacement of borate band was started in May 2001 and carried out on round the clock (RTC) shift basis. The isotopic analysis of the profile samples taken in March 2002 showed a peak enrichment value of 42.5% in $^{10}B$. After two more cycles of displacement (June, 2002), isotopic analyses of the profile samples showed a peak enrichment value of only 42.9% in $^{10}B$. Even after three months, further enrichment was observed to be very low. At this stage, detailed modeling studies were carried out to understand the process. The study indicated that there are two possibilities to enhance the enrichment i.e. by decreasing HETP or by increasing average enrichment in the borate band. Second option was adopted during operation. Enriched zone of the band was increased by 'Cut & Feed technique' that involves the removal of depleted portion of the borate band and loading of fresh natural boric acid to increase the inventory of $^{10}B$ in the band (Ref: IGC Newsletter Vol 56, April 2003, pp 2-3). Thereafter, frequent cut and feed operations were carried out without interrupting the displacement of the borate band. The results of samples taken in Jan 2005 showed a much-improved enrichment. The quantity of boric acid enriched in $^{10}B$ to 65% and above was 1 kg. Further displacement of the borate band was continued to enhance the quantity of boric acid enriched above 65% in $^{10}B$. The results of the analyses in March 2005 indicated substantial quantities of boric acid enriched to 65% and above in $^{10}B$. Accordingly, the product withdrawal campaign was carried out during April 2005. Samples were drawn at regular intervals during the product withdrawal and analyzed using Inductively Coupled Plasma Mass Spectrometer to ascertain the enrichment of boric acid above 65% in $^{10}B$. The concentration of enriched boric acid produced in BEP is 0.3 M. For conversion of enriched boric acid to elemental boron, it is required to convert the enriched boric acid solution into powder form. In order to make boric acid powder from boric acid solution, a tray dryer of standard design available in the market was procured and commissioned. The preliminary trials were carried out using depleted boric acid solution. These initial experiment showed that conversion losses in powder formation were up to ~ 30% , probably due to carry over of fine droplets of powder and a scheme was evolved to introduce an evaporator before the dryer to reduce the volume of boric acid by 70%. Efficiency of the dryer was also increased by selecting best possible operating conditions (temperature and fan speed) after carrying out trials. Accordingly, an evaporator was installed to concentrate boric acid solution and subsequently load the concentrated solution into tray dryer to form the powder. Fig.2 shows a view of the evaporator used for evaporating enriched boric acid solution.

Fig. 1 A view of Boron Enrichment Plant

Volume of the boric acid solution charged to the evaporator was about 100 litres per batch. When the liquid level in the evaporator came down to 30 litres, the evaporator was stopped

Fig.2 A view of evaporator used for evaporating enriched boric acid solutions

Fig. 3 A view of Tray Drier with powder in trays

and the solution was allowed to cool to room temperature. The evaporation was carried out for about 20 hours. About 70 litres of condensate was collected and analyzed for presence of boric acid. It was observed that the normality of condensate collected was 0.003 N indicating that there was negligible loss of boric acid (less than 1%) during evaporation. This condensate was drained. The concentrated boric acid solution was taken out of the evaporator, analyzed for concentration of boric acid and was charged to the trays of dryer.

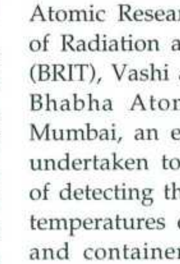
The Tray Dryer consists of 12 trays arranged in an insulated cabinet provided with heating coils and fan, which maintains a uniform temperature inside the cabinet. Fig. 3 shows a view of Tray Drier with powder in trays. By carrying out a few experiments, the operating conditions of the tray dryer were optimized for getting higher efficiency. The quantity of boric acid collected as powder was compared with actual boric acid loaded as the solution and it was found that losses came down to ~ 5% in the present evaporator - dryer system.

With this the technology for production of boron enriched to 65% in $^{10}B$ has been mastered. The next stage of conversion of enriched boric acid to elemental boron is in progress at the laboratories of the Chemistry Group.

(Reported by Dr. B.K. Sharma, Shri G.P. Sah, Shri G. Mohanakrishnan and Dr. C. Anand Babu, Separation Technology & Hydraulics Division, Fast Reactor Technology Group)

# FORUM
## FOR YOUNG OFFICERS

# Thermal Imaging for Detection and Quantification of Activity of Radioactive Sources in Shielded Casks and Containers

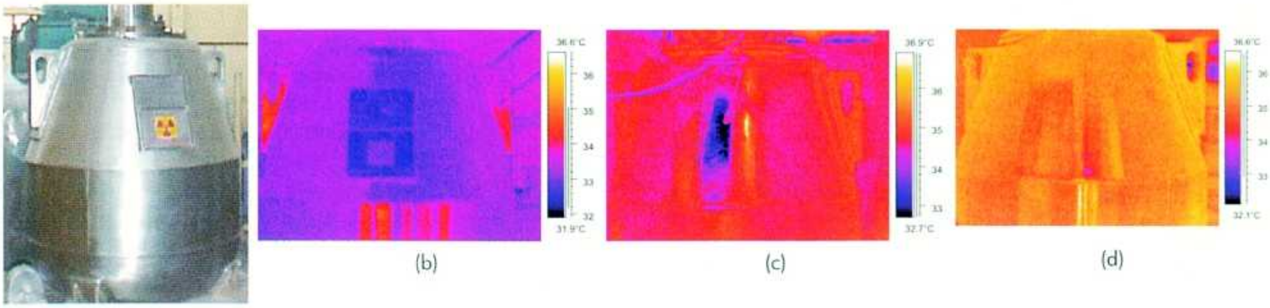


Ms. M.Menaka (DOB: 22.03.78) obtained her M.Sc. degree (Physics) from Madras University in 2000. She joined IGCAR directly as Scientific Officer (C) in January 2002.

Thermal imaging has been employed for the first time to detect containers or shielded casks with radioactive sources and also to estimate the radioactivity levels in the containers of same type, after appropriate calibration.

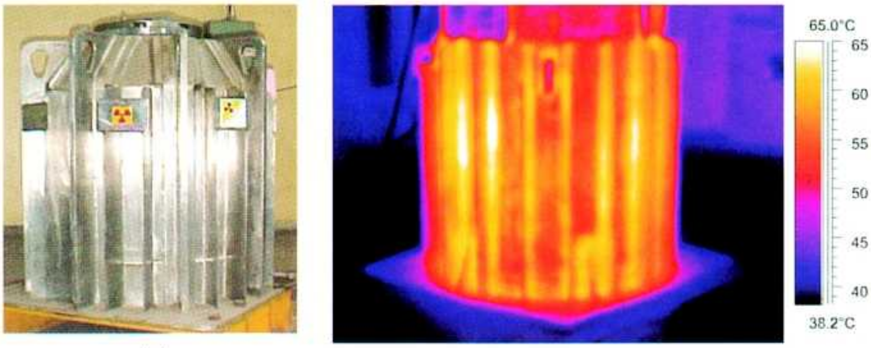
Thermography or thermal imaging or infrared (IR) imaging or infrared thermography is an advanced non-destructive testing technique used for mapping the temperatures profiles on the surface of an object. Based on the detection of infrared radiations emitted by the object, the technique is an indispensable tool in the field of predicitve condition management in electrical, petrochemical, steel and process industries. The technique also finds wide applications in the fields of materials characterisation, energy surveillance, energy audit. As part of a joint collaborative program between Non-Destructive Evaluation Division (NDED) of Indira Gandhi Centre for Atomic Research, Kalpakkam, Board of Radiation and Isotope Technology (BRIT), Vashi and Isotope Division of Bhabha Atomic Research Centre, Mumbai, an experimental study was undertaken to explore the feasibility of detecting the rise in the outer skin temperatures of radioactive packages and containers and correlating the same with the activity of the source.

Gamma heating of materials especially in shielding casks and transport containers used for handling highly radioactive sources is quite common.



(a) (b) (c) (d)

Fig.1 (a) Photograph of gamma chamber housed inside a blood irradiator and Thermal image of (b) an empty gamma chamber and gamma chamber with source of activity of (c) 700 Ci (d) 780 Ci.




(a) (b) Cask 2 ( 96,800Ci)

Fig 2(a) Photograph (b) Thermal image of the shielded cask

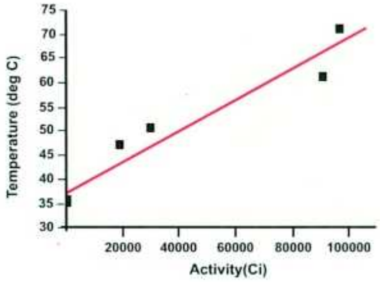



Fig. 3 Plot of the maximum temperature for various activity levels

This gamma heating is primarily due to absorption of the gamma rays and the conversion of photon energy predominantly to heat energy. The rate of heat generated per unit volume at a point z in the shield is given by

$$Q(z) = \int_E \mu_a(E)\phi_\gamma(z,E)E_\gamma dE \text{ MeV/m}^3\text{.s}$$

where $\mu_a(E)$ is the linear energy absorption for gamma rays of energy E, $E_\gamma$ is the energy of the gamma ray photon in MeV.

Blood irradiators containing Co-60 source with activity in the range of 700 to 800 Ci and shielded casks with Co-60 pencils and assemblies with activities ranging from 19 to 97 kCi were scanned using a focal plane array based thermal imaging system. By suitably evaluating the emissivity of the objects based on their surface condition and also by incorporating the necessary corrections for ambient temperature to compensate for IR radiations from other sources, the skin temperatures were determined. It is well known that the activity of the source decays with time. Since Co-60 was the isotope present in all the cases, appropriate correction for decay in the activity was also incorporated.

Fig. 1(a) is a photograph of the gamma chamber housed inside a blood irradiator and Fig. 1(b) shows the thermal image of an empty gamma chamber taken as baseline for comparison. Analysis of the thermal image of the gamma chamber with the source inside revealed a uniform isothermal temperature distribution with skin temperatures in the range of 306.3K-307.1K (Figs. 1(c & d)). Subsequently, thermal imaging of shielded casks with radioactive sources was carried out. Fig. 2(a) is the photograph and Fig. 2(b) is the thermal image of a shielded cask with Co-60 assemblies. One of the casks showed variation in the temperatures along the circumferential direction due to presence of four Co-60 assemblies with varying activities in the same cask. The peak temperatures along the circumference corresponding to the four Co-60 assemblies varied from 341K to 344K. Compared to the skin temperatures of the gamma chambers, the skin temperature of the shielded casks was much higher varying from 320K-345K. This is quite natural since the shielded casks housed radioactive sources with much higher activities. A plot of the maximum temperature vs activity for a given type of casks, shown in Fig.3 reveals a linear increase in the skin temperature with activity. This first of its kind study opens up a new application of thermal imaging.

Apart from estimating the activity of the radioactive source, it should also be possible to detect defective casks by this technique (an idea which has not been explored so far). Further experimentation in this direction and also to enhance the reliability of quantitative correlation is planned.

(Reported by M. Menaka and colleagues,
Nondestructive Evaluation Division,
Inspection Technology Group,
in collaboration with BRIT, Mumbai and
Isotope Division, BARC)

# Neutron Source Strength of Source Subassemblies for FBR - 500 MWe

Ms. M. M. Shanthi (DOB: 26.02.70) obtained her M.Sc. degree (Physics) from Madurai Kamaraj University in 1992 and M.Tech (Laser & Electro-optical Engineering) from Anna University in 1996. She joined IGCAR directly as Scientific Officer (C) in July 2001.

Reactor startup and operation in FBR-500 MWe is monitored using neutron detectors located on the lattice plate above the core. During normal operation of the reactor, the neutron flux at this location is sufficient to obtain measurable count rates. During reactor shutdown and fuel handling, the neutron flux at this location, due to the inherent neutron source arising from spontaneous fission in isotopes of U, Pu and Cm and ($\alpha$, n) reactions in light elements is very low. Hence, long counting times and consequently long start-up times are required. To obtain a minimum count rate of 3-10 cps at the detector location and hence to minimize startup time to within 5 to 6 hours, use of Sb-Be source subassemblies in the blanket row is envisaged.

Sb-Be is a photo neutron source. When antimony is irradiated, antimony-124 is produced. Sb-124 has a half-life of 60.9 d. It emits several gamma rays including 1.69 MeV gamma with 49% yield. Of these gammas, those above 1.67 MeV interact with Be-9 to produce neutrons (called photo neutrons). The nuclear reactions involved are shown below,

$$^{123}Sb + n \rightarrow {}^{124}Sb \rightarrow {}^{124}Te + \gamma$$

$$^{9}Be + \gamma\ (> 1.67\ \text{Mev}) \rightarrow {}^{4}He + n$$

In FBR, the source SA is planned to be irradiated during the first cycle of reactor operation. The SA consists of antimony pin bundle placed concentrically in the Be block. The pin bundle consists of 19 $Sb_2O_3$ pins with clad, with sodium flowing between the pins. The location of FBR source SA in the core is shown in Fig. 1.

To check the adequacy of the FBR source SA in providing the necessary count rate of 3-10 cps, an estimation of activation of Sb and the resulting neutron source strength from the SA has to be done. Normally neutron flux distribution in the core is done by 3D neutron diffusion/2D transport calculation. The 3D diffusion code CEMESH cannot perform neutronic calculation for hexagonal geometry. But for studying the effect of source subassembly, which has a hexagonal geometry, the exact geometry has to be modeled. This is possible with a code MCNP. MCNP is a general purpose, 3D Monte-Carlo neutron-photon transport code. This code takes care of the complex geometry of the source SA. Plan view of the geometry simulated in the calculations, generated by the code, is shown in Fig.2.

To validate the calculations, the configuration of the Sb-Be source used in two experimental set ups were simulated and their yields were compared with measured values.

In one of the experiments, an aluminum cylinder of length 5.08 cm outer diameter 2.22 cm and thickness 0.16 cm containing 98 g of Sb surrounded by 0.79 cm of Be was irradiated and the neutron source from Sb-Be was measured to be $1.5 \times 10^{7}$ n/s after one month, when the Sb-124 activity was 8 Ci. The neutron source estimated using MCNP was found to be $1.47 \times 10^{7}$ n/s, which is in good agreement with the measured value.

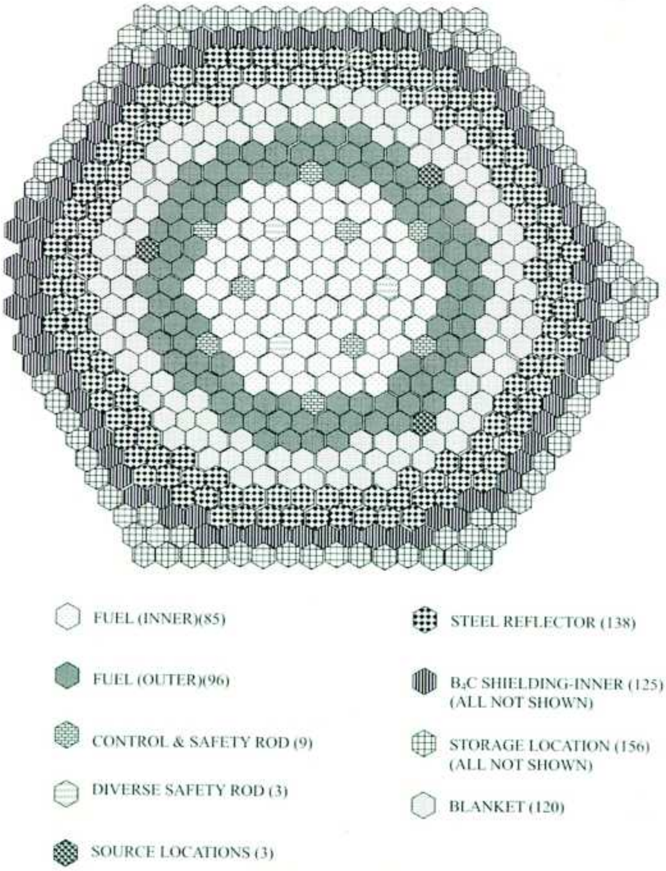



Fig.1 Core Map Showing Locations of Source SA

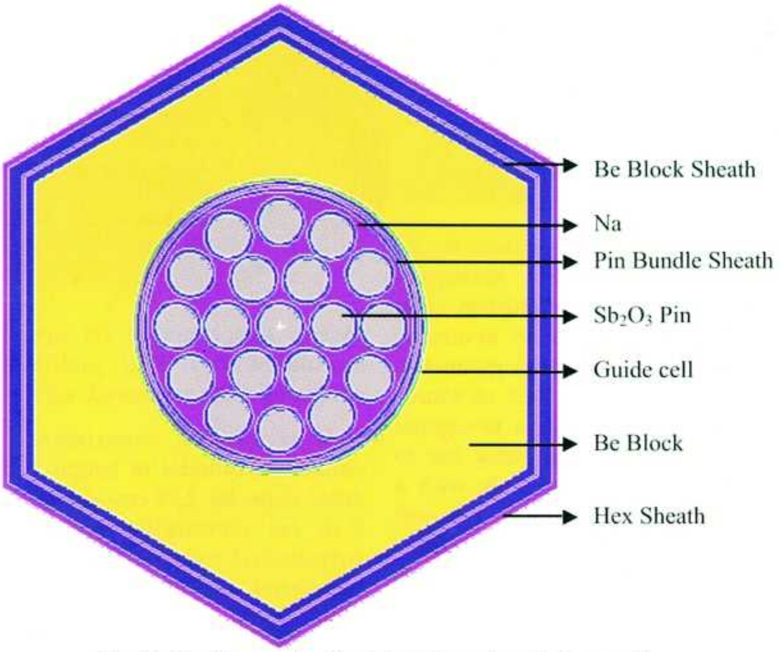



Fig. 2. Plan View of the Simulated Geometry with Source SA

The source employed in other measurement, corresponds to a configuration with a Sb cylinder of 5.08 cm length and 1.25 cm dia covered by 0.38 cm graphite, 0.11 cm brass and surrounded by a 0.79 cm thick Be. The neutron yield was estimated to be $1.72 \times 10^6$ n/s/curie compared to the measured value of $3.2 \times 10^6$ n/s/curie. The difference in prediction and measurement may be due to the uncertainty arising from non-availability of exact graphite and brass composition.

Using neutron flux and spectrum at the source SA location, neutron and gamma transport calculations were carried out in the source SA to estimate the activation of Sb and the resulting neutron source strength for an irradiation time of 185 d. The value of calculated neutron yield is $1.2 \times 10^{-4}$ n/s/$\gamma$ and that of the saturation gamma activity of Sb is 3.89 TBq/cc. These lead to a neutron source strength of $6.97 \times 10^{11}$ and $3.37 \times 10^{11}$ n/s per SA for 100 and 50 cm long Sb pins respectively. The estimated source strength of the SA is found to be adequate to obtain a minimum count rate of 3-10 cps at the detector location with 3 source subassemblies shown. Since 2 months of full power operation is required to fully activate the source, its effect will be felt only after two months of operation. Since the half life of $Sb^{124}$ is 60.9 days, even after shutdown, the source SA keeps on emitting neutrons. Hence, flux level at detector location is sufficient enough to restart the reactor with less startup time.

(Reported by Ms. M.M. Shanthi and colleagues, Reactor Physics Division, Reactor Engineering Group)


Madras Library Association - Kalpakkam Chapter (MALA-KC) and Scientific Information Resource Division (SIRD), IGCAR, have been conducting a series of conferences on "REcent ADvances in Information Technology". The conference will have invited talks by experts in the field and contributed paper presentations from Researchers. A pre-conference tutorial is being arranged for the benefit of Information Professionals on July 13, 2005.

**Call for Papers**

The conference will consist of invited talks and contributed papers. Contributed papers, on any of the following theme sub-topics are welcome.

**Theme**

Digital Libraries to Knowledge Systems

**Sub-topics**

Facets of Digital Library, Infórmation Management, Knowledge Manage-ment, Knowledge Sharing Techniques, Library the Gateway

**Important Dates**

| | |
|---|---|
| Pre-registration (with Abstract) | 14 May, 2005 |
| Intimation of acceptance of paper | 24 May, 2005 |
| Receipt of completed papers | 18 June, 2005 |
| Last date for registration | 30 June, 2005 |

Address for Correspondence
**Shri M. Somasekharan,**
Convener, READIT-2005
Head, Scientific Information Resource Division (SIRD),
IGCAR, Kalpakkam–603 102

Email: soma@igcar,ernet.in
Fax: 04114-280096




Published by Scientific Information Resources Division, IGCAR, Kalpakkam-603 102