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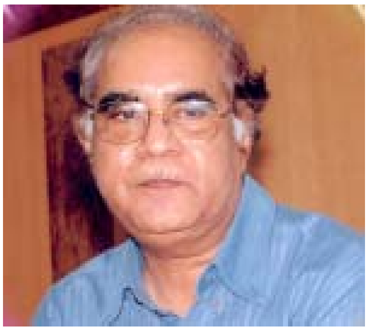
From the Director's Desk

TECHNICAL ARTICLES



DARE TO DREAM:

THE STORY OF THE METALLURGY AND MATERIALS PROGRAMME

In December 1973, Dr. G. Venkataraman came on transfer from Bhabha Atomic Research Centre(BARC) to the then Reactor Research Centre (RRC), to initiate research in Materials Science. The Materials Science Laboratory formally came into being early 1974 with only two members – with the other member on deputation to Atomic Energy Research Establishment, UK. Soon however other members came on transfer from BARC and Tata Institute of Fundamental Research (TIFR) to join the laboratory. In June 1974, I landed in Kalpakkam with four of my colleagues from BARC, and within two weeks, Dr. Placid Rodriguez came with three of his colleagues to take charge of the Metallurgy research. The mandate was to plan and build a metallurgy R&D programme in support of fast reactor technology, including the post-irradiation examination facility. The facilities had to be built from scratch; only six creep testing machines (jocularly referred to as the "dowry") had been transferred from BARC to RRC. The then Project Director, Shri N. Sreenivasan provided all support and guidance for these two nascent activities. He also made his expectations very clear; he would accept nothing but the best – be world leader in your chosen area of expertise. Thus began the saga of what we see to day as the Metallurgy and Materials Programme.

Right from its inception, the Metallurgy Programme was conceived with a holistic and far sighted approach: it would be developed to meet all the metallurgical R&D needs identified or anticipated for future. I was entrusted the challenging task of planning, design and operation of the hot cell facilities, and also developing and validating testing facilities for their eventual deployment in the hot cells, which has now matured into a premier facility. A comprehensive mechanical metallurgy laboratory has been systematically built up over the years, with extensive creep and low cycle fatigue, fracture mechanics testing, and laboratory scale melting and fabrication facilities. These were meant to cater to the needs of not only our Centre, but the DAE family as whole. All relevant areas, such as corrosion metallurgy for both water and sodium environments under the guidance of Shri J. B. Gnanamoorthy, and a comprehensive physical metallurgy facility for structure property correlation and basic researches in phase transformation, were planned right from the inception. Thermodynamics and kinetic studies were also added a few years later under the leadership of Dr. O. M. Sreedharan. Planning and implementation of the Materials Sciences

Programme on the other hand was spearheaded by Dr. G. Venkataraman, focusing and building expertise in a few select areas: nuclear techniques, defect and radiation damage studies, light scattering and X-rays, and high pressure physics, backed by a theory group. Within a few years, researches in low temperature physics started with setting up cryogenic facilities. Strengths of these two programmes gradually increased, with a few transfers from BARC and TIFR, fresh inputs from the BARC Training School, and direct selections to the programmes.

There were some common traits between Dr. G. Venkataraman and Dr. P. Rodriguez in their approaches to science management – *lead from the front, throw challenges to bright young minds, dare them to dream, and provide every support for them to expand their horizons. In this regard, both bore the unmistakable signs of DAE legacy*. Doing one's Ph.D. working on the departmental projects

Today, Metallurgy and Materials Group has 82 Ph.D degree holders, of which more than 75% have acquired their PhD degrees from the premiere academic Institutes like IITs, IISc, BHU etc, and two even from the University of Saarland, Germany, in this manner.

became (and continues to be) quite commonplace in the programmes. Today, Metallurgy and Materials Group has 82 Ph.D degree holders, of which more than 75% have acquired their PhD degrees from the premiere academic Institutes like IITs, IISc, BHU etc, and two even from the University of Saarland, Germany, in this manner. There was one more, and in many ways a unique, reason for the rapid maturing of these two programmes. This is the continuous interactions with the teams engaged in building the FBTR, and since the mid eighties, also designing and then developing technologies for the 500 MW(e) FBR. This has served a crucial purpose – at no point of time did research become "Ivory Tower research" – everyone is sensitive to the fact that all research must be useful to FBR and other DAE programmes, and in the event of it does not, it must be of world class.

The result of such enlightened management, and also support in the formative years is a group of scientists and engineers with head high up in the sky but feet firmly on the ground! They are carrying out high quality research, contributing to DAE programmes, and making their mark in the national and international arena. They are also daring to dream – to build from strength into new areas not planned earlier. Materials Sciences Laboratory became part of the Metallurgy Programme in 1985, when Dr. G. Venkataraman left IGCAR after an illustrious career, and Dr Placid Rodriguez took charge of overall leadership of the Metallurgy and Materials programme. Dr. Kanwar Krishan played an important role of an affectionate and caring Mentor for Materials Science activities. In 1992, Dr Placid Rodriguez passed on the baton of leading the Metallurgy and Materials programme to me, when he took charge as the Director of this Centre. I have passed on this important responsibility of nurturing the Metallurgy and Materials programme to Dr. S. L. Mannan in 2004. One must also gratefully acknowledge the patronage (well earned, one might add!) of Shri C.V. Sundaram and successive Directors of this Centre.

I had realized that it is necessary to consciously guard against complacence, a possible pitfall for any successful research group with national and international recognition, and also enhance collaboration with competent national and international groups with matching interests and programmes. I have recently written extensively, in the earlier issue of IGC Newsletter on the IGCAR-Research-Academia linkage. I have also placed enhanced emphasis on mentoring young professionals, and giving challenging assignments to the mature scientists and engineers. We have recently carried out in our Centre, a detailed mentoring exercise for young engineers and scientists, to motivate and nurture their young talent, which is considered as an unique and novel exercise in DAE units. I consider that human resources with comprehensive R&D facilities are the keys to delivering mature fast reactor technology to the country, and indeed for any meaningful science and technology programme. I have written a precise but comprehensive article in International Union of Materials Research Society's Newsletter on R&D Programmes of the Materials Programmes of the Centre. This would appear in November 2005 issue of IUMRS Newsletter (hardcopy and website simultaneously). Thus, I would not repeat these details in my current article.

Success is inevitable with such a combination of a dedicated group of R&D researchers, sensitive about their mandate, proud of their achievements, and always aspiring for more, an enlightened management, and the symbiotic interactions. And given the ever-widening spiral of greater success bringing in its wake both increased support and enhanced demands, the phenomenal growth of the Metallurgy and Materials Programme in its three decades of its existence is equally inevitable. Comprehensive expertise and core competence have been developed in various facets of materials science and technology such as modeling, manufacturing, testing and complete

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characterization of structural materials. Also considerable experience has been gained in design, construction and maintenance of hot cells and in-cell equipment in the process of building up a state-of-the-art post-irradiation examination facility, with equipment such as visual examination, dimensional measurements, eddy current testing, X-radiography, neutron radiography, both prototype and miniature mechanical testing, radiochemical methods etc. A recent achievement of this facility is the examination of carbide fuel from FBTR that has seen a burn up of 100 GWd/t. By the late seventies, it was strongly felt that an advanced expertise base needs to be set up to cater to the ever increasing, and often challenging, existing and anticipated NDE requirements of the DAE family. It would adopt and adapt and improve upon conventional techniques, and harness the emerging "esoteric" NDE methods for practical applications. Commissioning of the Kamini reactor for neutron radiography was only part of the story. Today, the Metallurgy and Materials Programme can justifiably boast of a world-class school for R&D in NDE research. Its field of research includes conventional techniques, and also advanced techniques like acoustic emission, X-ray diffraction, magnetic/acoustic Barkhausen noise, infrared thermography, ultrasonic and eddy current imaging, residual stress measurements; development of various NDE probes, transducer and instruments for various critical applications, and even development of ferro-fluid based sensor for magnetic flux leakage measurement. Matching R&D facilities have been set up, making it one of the best such laboratory anywhere in the world. The range of applications is equally impressive: in structural integrity assessment and life extension, in-service-inspection (ISI) of components for heavy water plants; nuclear reactors and fuel cycle facilities; defect and microstructural characterisation; in-situ structural transition and defect detection in support of in-service inspection and intelligent material processing and welding; advanced signal analysis and development of knowledge-based decision support systems; mathematical modeling/simulation; and image analysis.

The same catalysts can be identified for the spectacular growth and contributions of the other metallurgical research laboratories. The R&D facilities are recognized as amongst the most comprehensive amongst other similar Research Centres. The mechanical properties assessment laboratories now house a battery of creep testing units, facilities for low cycle fatigue, creep-fatigue interaction and thermo-mechanical fatigue testing, instrumented drop weight and impact testing units for dynamic fracture studies, and facilities for quasi-static fracture mechanics and fatigue crack growth studies at ambient and elevated temperatures. The early researches on dynamics of plastic deformation particularly dynamic strain ageing, mechanistic and predictive aspects of creep, low cycle fatigue and creep-fatigue interactions, and dynamic fracture studies brought international recognition. The international popularity of the series of four International Conferences on "Creep, Fatigue and Creep-Fatigue Interaction" hosted so far at a regular interval of four years is a testimony to the recognition of our strength in this field. Today the scope of research has multiplied manifold, encompassing detailed evaluation of the properties relevant to FBR technology particularly the 500 MW(e) FBR, their dependence on microstructure, researches into fracture and damage mechanics for current and future applications, and numerical modeling and simulations for correlation and extrapolation. Studies in metal forming and tribology include development of critical materials, near net shape forming, studies on thermo-mechanical processing, modeling and simulation for material processing and microstructure evolution, and fretting and wear studies for FBR applications. Since the nineties, a dedicated group is involved in the problems of science and technology of welding and hardfacing for FBR and fuel reprocessing applications. Its scope of research includes weldability studies, indigenous development of specialized welding consumables, technology development for dissimilar metal welding, hardfacing and surfacing, in-situ and off-site repair welding of power plant components, development of Activated TIG welding, and intelligent welding. Facilities are being added to tribology and welding laboratories to meet these increasing demands. Physical metallurgy research includes comprehensive characterization of materials for the present and future FBR and reprocessing plant applications, development of various advanced electron-microscopy techniques, development of hard coatings and boriding techniques for FBR and reprocessing applications, future radiation detector materials, and modeling for structural systematics. The facilities include a comprehensive optical and electron-optical laboratory with an analytical transmission electron microscope and a high resolution transmission electron microscope, X-ray diffraction, chemical and plasma vapour deposition, laser ablation, and magnetron sputtering. The corrosion studies for fast reactor, power plant and reprocessing plant applications include stress corrosion and corrosion fatigue, generalized and localized corrosion, high temperature oxidation, bio-fouling, basic studies in surface sciences, surface modification techniques for improved corrosion resistance, and corrosion monitoring. Apart from two dynamic liquid sodium loops and corrosion fatigue machines, all conventional characterization facilities are also added. Necessity dictated creation, in the nineties, of a small, dedicated team devoted to tackle innovative design and engineering problems like capsules for in-reactor experiments including in-reactor creep testing, study and modeling of thermal cycles and residual stresses in welding, precision machining and welding of small size components, and generation of precision calibration standards for NDT equipment.

Materials Science Research in IGCAR has earned respect for its solidity and also balanced emphasis on experiments and theory. The emphasis on indigenous development of research grade instruments and experimental set ups led to several 'firsts': a He-Ne laser for a Raman scattering setup, a positron life time setup which was followed by an angular correlation apparatus, Tandem Van de Graaf accelerator, diamond anvil cell for high pressure X-ray research, high tonnage press for studying pressure induced phase transitions and amorphisation, X-ray spectrometer, an internal friction setup, several liquid nitrogen and helium cryostats for low temperature physics studies. In the early years, Dr. K. P. Gopinathan had played a key role in the indigenous nuclear spectroscopy developmental activities. This aspect of self-reliance has been a guiding factor in the subsequent phenomenal growth of all the facilities. For example, the particle irradiation facility that started with a neutron generator today houses 1.7 MV Tandetron Accelerator, various facilities for ion implantation, Rutherford Back Scattering (RBS), Channeling, Particle Induced X-ray Emission (PIXE), and Hall Effect measurements. Some of the other unique and world-class facilities are: an indigenously developed variable energy positron beam system, a very sophisticated X-ray diffractometer with low and high temperature attachments, novel materials synthesis under megabar pressures and high temperatures etc. Subsequently, thermal desorption on alloys and compounds was another new area of research which catapulted the research into the area of sputtering and surface science. A Secondary Ion Mass Spectrometer (SIMS) was installed to look at depth resolved compositions in metals and alloys at sensitivities in the ppb level. In course of time, important activities have been added to the materials science research program. In the mid-eighties, it was decided to considerably expand the scope of research on superconducting materials, to encompass both basic research in the emerging exciting field of high temperature superconductivity, and superconducting quantum interference device (SQUID) based sensor development. This necessitated comprehensive expansion in the facilities, including fabrication facilities for micro-fabrication for feature sizes down to 1 micron, and for thin film based SQUID fabrication, and laboratory for device characterization and utilization. Dr. T. S. Radhakrishnan had caringly nurtured these SQUID application activities, as well as provided leadership for materials science programme. Subsequently, Dr. B. Viswanathan took over the mantle of Materials Science activities and jump-started the accelerator-based radiation damage programme on reactor alloys.

Application of a variety of experimental and theoretical techniques to study the same system, backed by rigorous theoretical studies has led this laboratory being internationally recognized as a leader in many areas of research. The research on positron annihilation threw new light on the early stages of point defect clustering, helium bubbles in metals and alloys and phase transitions in Al alloys. Outstanding research in the area of light scattering in colloidal systems has lead to the discovery of phase separation based on the ionic impurity concentration, opening up a vast area of research. The high pressure research in lanthanide and actinide based alloys and other AB_2 type intermetallics like $LaAl_2$, UAl_2 and $ThAl_2$ attracted worldwide attention. The field of high temperature superconductivity spawned a host of research into materials and properties of YBCO and related compounds. Pioneering work on doped superconductors, and the natural extension to Fullerenes ensured that this laboratory stayed at the forefront of low temperature basic research. Studies with the variable energy positron beam system for defect studies at different depths ranging from a few nanometers to microns has thrown new lights on the phenomenon of irradiation embrittlement of steels and metal-semiconductor junctions. SIMS is being used for many critical studies including carbon and nitrogen profiles in austenitic stainless steels, phenomenon of implantation, and diffusion in thin films. Researches in theoretical physics have been equally outstanding. For example, application of novel techniques like fluctuations and non-linear theories gave new insights into defect and their interactions. The theory of "defect ordering" was initiated using the principles of fluctuations and bifurcation. An exciting new area of study undertaken is the application of Monte Carlo techniques for porous media. The expertise developed in experimental physics has proven to be crucial in the success in many developments in areas of technical physics: SQUID - based technology for basic research and NDT, image plate scanner for filmless radiography, and development of Micro-Electro-Mechanical Sensor (MEMS) - based ultrasonic transducers for a NDT applications. A recognition of the formidable strength and achievements in the area of SQUID technology is that we are collaborating with National Institute of Mental Health and Neuro Sciences (NIMHANS), Bangalore, in a DST-sponsored project, for setting up of a SQUID based magneto encephalography (MEG) system for non-invasive studies of human brain.

Under the prevailing international embargo scenario, building up of the facilities and expertise has been challenging to the utmost. A popular adage says: *"When the going gets tough, the tough get going"*. This has always been the culture in DAE, and the Metallurgy and Materials Group is no exception. One example from the early eighties is the successful development of equipment of high reliability for post-irradiation examination. There are many, many more examples of such successes throughout the years. Comprehensive self reliance, particularly in the critical sectors, has always been one of the key guiding principles. The successful indigenous development, in collaboration with industry, of austenitic SS 316L(N), modified grade 9Cr-1Mo (P91), and ASTM A48 P2 steel plates, and also the welding consumables for the SS 316L(N) and P91 grades, with properties matching or excelling those for the internationally available products, are recent examples of this approach. Most of the research

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programmes in metallurgy were undertaken to meet immediate and specific requirements for the 500 MW(e) FBR and the fuel reprocessing technologies. In turn, as the pioneers envisaged, the contributions from this Group have been outstanding from its very inception. Over the years, the contributions cover every facet involving metallurgy and materials: materials selections, indigenous development of special materials, development of melting and fabrication routes, characterization of creep, fatigue, fracture, corrosion, and tribological and fretting properties, life prediction and extrapolation, welding and hard-facing for the FBR components, development of specialized techniques for pre-service and in-service inspections, robotics and automation, the examination of fuel pins irradiated in FBTR, and computational modeling. The most heartening aspect of the programme is that technological opportunities have led to "science", i.e., basic understanding, as reflected in numerous high quality research publications in reputed journals and important conference proceedings, earning prestige for the individuals scientists as well as the research groups, which are now internationally recognized.

The rapidly growing expertise of these programmes have been recognized, and sought after, by the entire DAE family since the very early days. An example from the early eighties is the instrumented impact testing of irradiated Charpy specimens of ASTM 203 Grade D steel (the initial RAPP end shield material); this was carried out in the fracture laboratory of IGCAR, the first time such test has been carried out in the entire DAE family. Indeed, from the very inception, Metallurgy and Materials Group has been making available its expertise to various units of DAE like Nuclear Power Corporation, Heavy Water Board, Nuclear Fuels Complex etc. in various areas like integrity assessment and NDE, life assessment and rejuvenation, failure analysis, welding metallurgy and in-situ repair welding, and specialized testing and consultation. The recent in-reactor creep testing of Zircaloy carried out in FBTR is one more link in the same chain. The expertise of the NDE group has found its use in such diverse and critical areas like NDE based damage and fitness-for-purpose evaluations and life extension of engines, aircrafts and helicopters of the national defence sector, and of rocket motor casing, satellite tanks etc. for the national space program, archeo-metallurgy and national heritage preservation, and even in small scale industries. The expertise of other research groups are being sought from time to time by National Thermal Power Corporation, the petrochemical sector etc. in critical issues. As I have recently described in these pages, the various laboratories in the Group have been actively participating in many important collaborative efforts with several leading academic and research institutes in India as well as in France, Germany and the United States under various programmes sponsored by IGCAR, DAE, Board of Research on Nuclear Sciences (BRNS), Department of Science and Technology (DST), and various international bi-lateral collaborations. Since many of the facilities available are rare, if not unique in this country, we have been welcoming and indeed encouraging their utilization by scientists both within DAE and outside DAE, particularly the student community. This has also considerably strengthened the interactions with other reputed institutions.

Since many of the facilities available are rare, if not unique in this country, we have been welcoming and indeed encouraging their utilization by scientists both within DAE and outside DAE, particularly the student community. This has also considerably strengthened the interactions with other reputed institutions.

It is quite natural that with such strength and reputations, recognition in the form of honours and awards, both national and international, has come to young and not so young scientists and engineers in the Group in good measure. What however I wish to specially mention is the honours, in the form of DAE Meritorious Service Awards, to many of the supporting technical staff: S/Shri T.M. Mohamed Koya, K. Jayakumar, C. Balan, S. Francis Rajan, N. Chellam Thevar, (Smt.) M. Radhika, A. Vincent Paul Raj, and M. Kuppusamy. This is an indication of the R&D environment prevailing in the group. It also underscores a factor often ignored: the supporting technical staff has to be nurtured to play a key role for any ambitious R&D programme to succeed.

If one has to identify the one factor that is responsible for the glorious success of the Metallurgy and Materials Programme in thirty one years of existence, it is the ability to harmoniously synthesize the twin roles of operating in the "research mode" and the "mission mode". This has inculcated a tremendous sense of responsibility to IGCAR, DAE and the nation without curbing scientific aspirations in any way, promoted team work, and led to R&D that is both relevant and excellent. This is also the reason for the youthfulness of the Group: *it is now thirty one years young, and I have no doubt that as long as the members of this Group do not lose sight of this basic fact, and dare to dream, it will continue to be young for many more decades to come.*

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Baldev Raj
(Director)

Analysis of Grid Plate towards remaining Life Assessment of Fast Breeder Test Reactor

Fast Breeder Test Reactor (FBTR) is operating with 28 Mark I fuel subassemblies, 13 Mark II fuel subassemblies and 1 PFBR fuel subassembly (FSA). As a long-term measure, it is now proposed to use a hybrid core (26 Mark I subassemblies in the central core surrounded by 52 MOX subassemblies). The actual dose experienced by the grid plate so far is equivalent to the dose that would have been experienced with hybrid fuelled reactor, operating at 30.7 MW_t over a period of 0.5 Effective Full Power Year (EFPY). A detailed analysis has been carried out to assess the remaining life of grid plate.

In the reactor assembly (Fig.1), the grid plate structure does the important function of supporting and guiding the subassemblies (SA) and also the entry of sodium in to the core. This structure consists of support plate (SP) and guide plate (GP), joined by an intermediate shell. The material of construction is SS 316. The SP carries the entire load of SA while GP provides guide to maintain the verticality of the SA. The mechanical load acting on the GP is negligible. However, the GP sees high neutron irradiation in the hybrid core configuration to the order of 1.72×10^{21} n/cm^2/y, compared to the flux of 2.69×10^{20} n/cm^2/y for SP. Thus GP is critical w.r.t neutron irradiation, and is analysed for various failure modes viz. loss of ductility, accumulated inelastic strain due to constraints of free expansion and overall deformation of plate, which in turn affects the verticality of the SA, the frictional force at the button and handling operation due to excessive tip displacement. The loss of ductility has been derived from the literature depending upon the accumulated fluence and the plate deformation due to void swelling and irradiation creep was determined by finite element analysis using software CAST3M, issued by CEA, France.

If the GP had been free at the periphery, it would have deformed freely under irradiation swelling. The end stiffness provided by the intermediate shell at the outer periphery, results in bending of GP. The free bending is restricted by the presence of control rod support sleeves, which is clear from the deformed shape (Fig.2). In this process, the sleeve develops a tensile load of 9710 N. The maximum vertical displacement of the GP is 1 mm. The inner portion of GP deforms downwards while the outer portion deforms upwards. This leads to

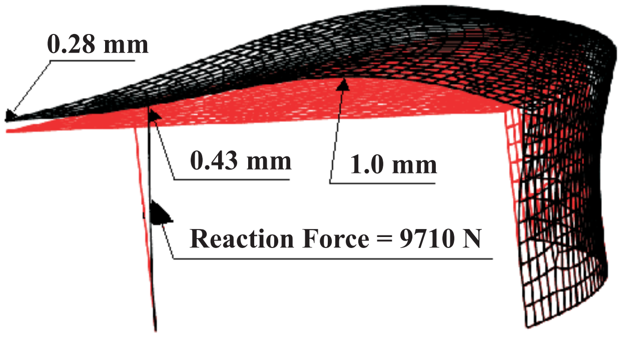


Fig.2: Deformed shape of GP after 20 EFPY

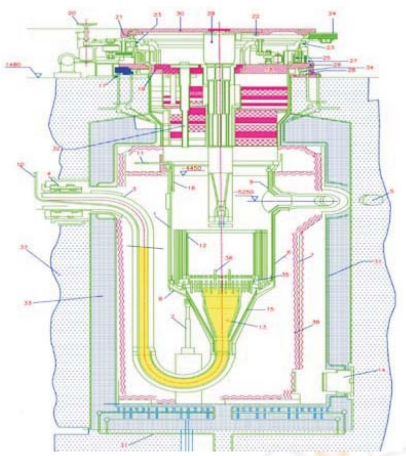


Fig.1: Reactor assembly

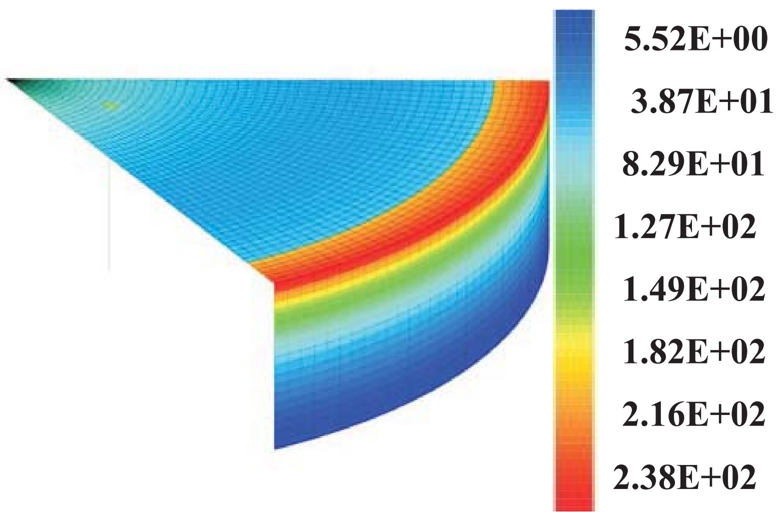


Fig.3: Von-Mises stress distribution without considering relaxation during 20 EFPY

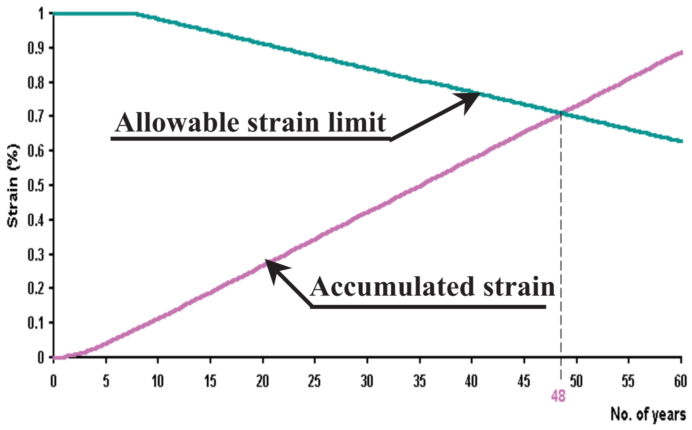


Fig.4: Accumulated strain variation

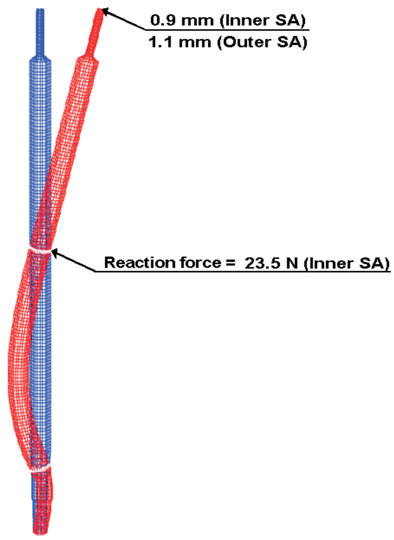


Fig.5: Deformed shape of a typical SA (After 20 years)

compacting of the inner sub assemblies and flowering of the outer sub assemblies.

The neutron irradiation causes a loss of ductility in stainless steels. The design limit of 10% total elongation at the end of life is considered, to safe guard against brittle fracture. Accordingly the acceptable dose is $2.0x10^{22}$ n_o / cm^2. The fluence of the GP is $1.717x10^{21}$ n_o/cm^2 per year, and the corresponding safe period is 11.5 EFPY.

For the structural material, having dose rate <5 dpa, the cumulative strain limit is 1.0%. In the hybrid core, the neutron dose seen by the clad for the target burnup of 150,000 MW d/t is 76 dpa. For the clad material, the thermal creep strain and plastic strain limits during steady state and transient operation should be 0.2 and 0.3%, respectively. Since the GP dose rate falls below the dose rate of clad material and above 5 dpa, the allowable strain limit has been interpolated as a function of time based on the accumulated dpa. The accumulated strain in the GP at any point of time shall not exceed this allowable limit.

The Von-Mises stress distribution in the guide plate at the end of 20 years without any creep relaxation is shown in Fig.3. It is used for computing the accumulated strain as a function of time. The allowable strain limit and the accumulated strain as a function of time have been plotted in Fig.4. Based on this the safe operation is arrived as 48 EFPY.

The tip displacement of control rod SA is obtained by separate analysis (Fig.5). The allowable life is 18.5 EFPY corresponding to 0.84 mm tip displacement (allowable slope of $5x10^{-4}$). Total allowable misalignment for core SA is 6 mm from the fuel handling consideration. A value of 1 mm is apportioned to account for the tip displacement of SA due to the swelling of guide plate and the corresponding allowable life is 22 EFPY.

Because the displacements are constrained at the button location, the resulting reaction forces produce frictional force of about 25 N, which is less than the allowable value 1000 N for ensuring smooth fuel handling operation. Hence it is not governing the life.

Based on the above conservative investigation, it is concluded that FBTR can operate still for a period of 11 EFPY using hybrid core. However, longer life is possible by reducing the fluence through provision of enhanced shielding at the bottom of SA. It is also recommended to introduce surveillance coupons at appropriate locations to determine the radiation damage.

(Reported by R.Suresh kumar, R.Srinivasan, P.Chellapandi and S.C.Chetal, Reactor Engineering Group)

"... There is a need for a constant interplay between basic sciences, technology and industrial practice if economic progress is to result from the activity undertaken. The wearing of several hats by the same person and the mobility of personnel from one type of activity to another have provided the impetus for growth in the projects of the Department of Atomic Energy... "

- Vikram A. Sarabhai

Detection and Evaluation of Sensitisation and Intergranular Corrosion in Austenitic Stainless Steels by

Eddy Current Testing Method

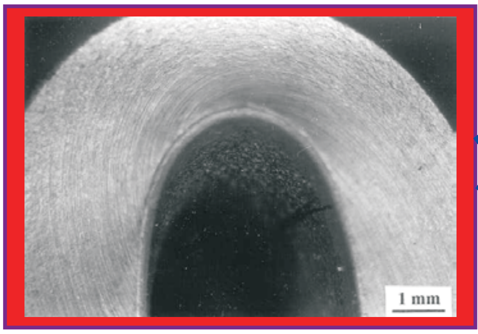
The structural integrity of austenitic stainless steel components is affected by various material degradation processes such as intergranular corrosion (IGC), stress corrosion cracking (SCC), pitting corrosion, creep and fatigue damage. It is essential to detect and evaluate the degradation by periodic inspections of the structural materials and components in operating plants either on-line or during shutdown. Sensitisation of austenitic stainless steels (SS) is a major problem during welding or high temperature service. It occurs when austenitic SS is heated or cooled slowly in the temperature range of 723 to 1123 K, which causes depletion of chromium (Cr) to less than 12% in the region adjacent to the grain boundary due to the precipitation of a continuous network of Cr-rich $M_{23}C_6$ carbides. In molybdenum (Mo) containing austenitic SS, these Cr-rich $M_{23}C_6$ carbides also contain Mo, thus causing a depletion of Cr+Mo in the grain boundary region during sensitisation. When a sensitised stainless steel is exposed to a corrosive environment, these depleted grain boundary regions dissolve, leading to a host of corrosion problems such as IGC and intergranular SCC (IGSCC).

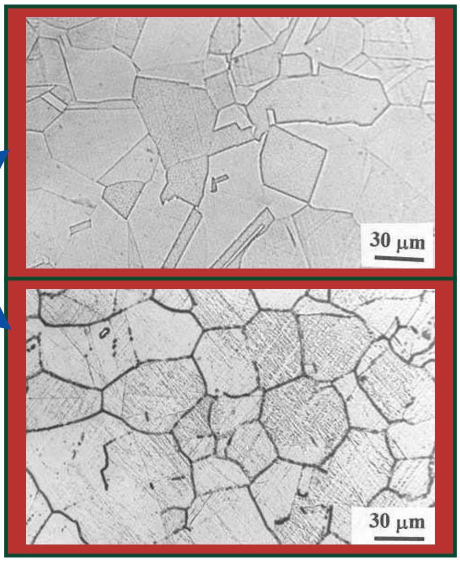
ASTM standardised tests (ASTM Standard A 262 Practice A to F), which are chemical in nature, are used to evaluate IGC caused by sensitisation in austenitic SS. These tests are commonly used to qualify/accept a component during purchase/fabrication stage. However, non-inclusion of acceptance limits in these standards leaves the interpretation of results open to users. Besides not quantifying the degree of sensitisation (DOS), these tests are also destructive and slow – a situation that is not welcome at plant site. To overcome these limitations of chemical tests, an electrochemical technique, known as electrochemical potentiokinetic reactivation (EPR) technique, was developed and standardised by ASTM (ASTM G108) to quantify DOS. This is a quantitative, non-destructive and rapid method, which is essentially suitable for field use. The EPR technique provides a criterion to identify the complete absence of sensitisation and, thus, is useful in quality control of fabricated components. However, it does not readily provide an acceptance criteria if a certain DOS is present in the material. Despite all efforts, EPR technique has not shown much of its early promise as a tool for quantifying DOS. This is because of (i) its high sensitivity to the changes in chemical composition of the SS, and (ii) inconsistencies in the correlation between ASTM Practice A262E and EPR DOS results due to effects of aging temperature, which does not permit a threshold DOS to be defined. These drawbacks in the EPR technique call for applying alternate NDT technique to unambiguously quantify DOS. Eddy current testing (ECT) presents a viable alternative due to its high sensitivity to changes in electrical conductivity/ permeability. We describe a laboratory study wherein an attempt was made to detect and quantify DOS and IGC in AISI type 316 SS by the ECT technique. In this study, heat treated rectangular specimens of AISI type 316 SS were subjected to ASTM A262 Practices A and E tests, EPR tests and ECT tests. Optical microscopic examination in as-polished condition after exposure to Strauss test solution was also carried out to determine the depth of attack by the Strauss test solution.

Bend test, after exposure to modified Strauss test solution, was used as a criterion to categorise the DOS, which was then correlated along with the microstructures to the values of EPR parameters and EC amplitude. Here it would be important to mention that in the oxalic acid etch test (ASTM A262 Practice A test), the $M_{23}C_6$ carbides are dissolved on electrolytic etching, while in modified Strauss test solution, the chromium deleted regions are attacked and not the $M_{23}C_6$ carbides. In oxalic acid etch test, qualitatively three microstructures are possible viz. ditch structure corresponding to continuous $M_{23}C_6$ carbide precipitation, dual structure corresponding to discontinuous $M_{23}C_6$ carbide precipitation and step structure corresponding to absence of $M_{23}C_6$ carbides. Based on the appearance of the bent region, the aged samples were categorised as (a) unaffected, (b) fissured, (c) cracked, and (d) broken. Figure 1 shows the different categories with corresponding microstructures. It is seen that for specimens that were broken or cracked, a ditch structure was seen; while for fissured specimens, a dual structure was observed. Unaffected specimens showed two types of structures either a step structure or a fully ditched structure. Aged specimens which showed ditched structure remained unaffected during bend test since the grain boundary Cr-depletion is self-healed with time by diffusion of Cr to the grain boundary area from the bulk of the austenite grains. Examination of as-polished surfaces exposed to Strauss test showed grain boundary attack to a certain depth only in the cracked or broken specimens, as shown in Fig. 2, with the depth of attack being more in the latter.

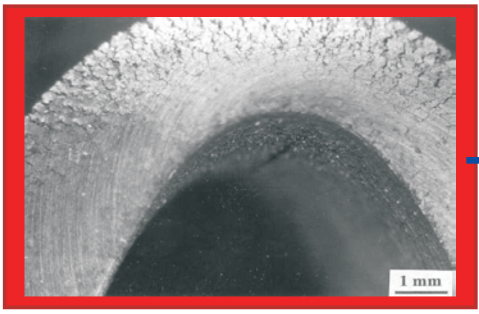
Category based on microstructure

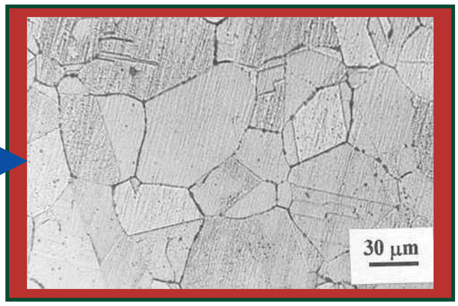
Unaffected



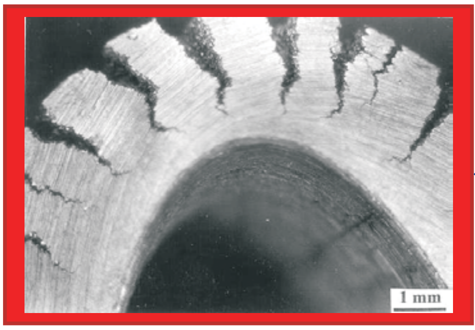


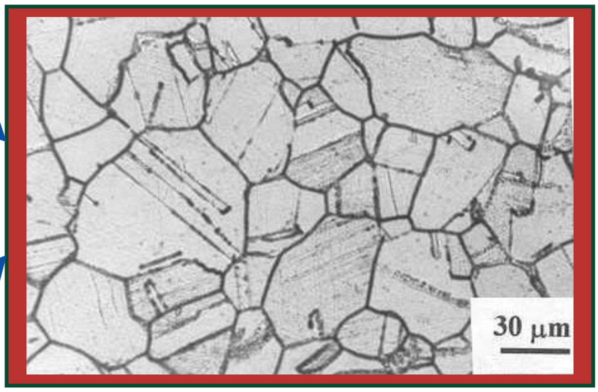
Fissured





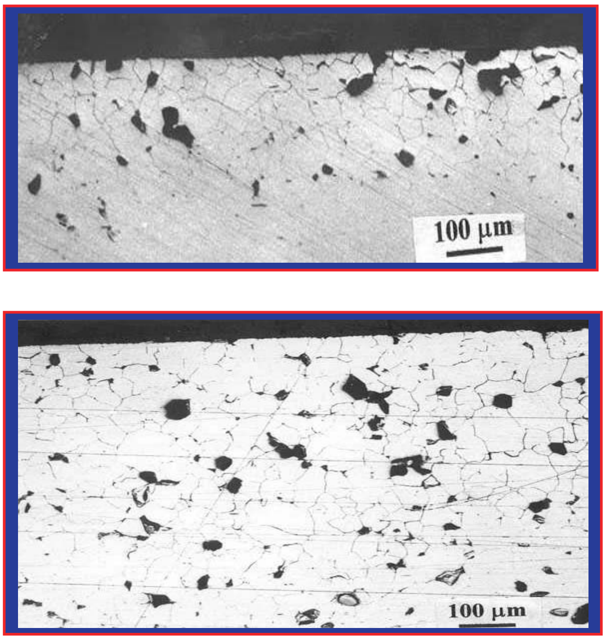
Cracked





Broken

Fig. 1: Categorisation of DOS based on bend test after ASTM A262 Practice E test and corresponding microstructures



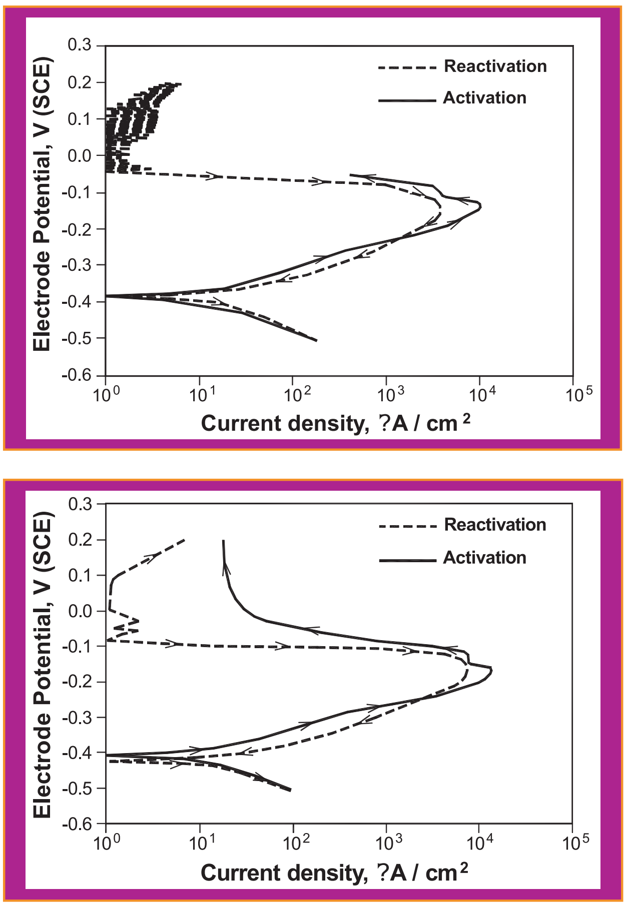
(a)

(b)

Fig. 2: Micrographs showing depth of attack caused by the Strauss test solution in (a) specimens showing cracks, and (b) in broken specimens

The results of EPR tests, depth of attack and ECT corresponding to the various categories are detailed in Table 1. The EPR tests were carried out by the double loop technique because this method automatically compensates for changes in alloy composition and also for differences in surface finish. The ratios of peak current densities during reactivation (I_r) to activation (I_a) and reactivation charge (Q_r) to activation charge (Q_a) were used as assessment parameters to evaluate DOS. Table 1 shows the range of the ratios of Q_r/Q_a and I_r/I_a for unaffected, fissured, cracked and broken categories of DOS. As per the standards prepared by International Standards Organisation (ISO) for evaluation of IGC susceptibility by means of double loop EPR test, values of $I_r/I_a * 100 > 5$ show medium to strong susceptibility to IGC. Based on this, it can be inferred that the aged specimens that showed fissures or remained unaffected after bend tests were not sensitised. Figures 3 (a) and (b), which represent the EPR curves for the cracked and broken categories of specimens, show that on activation potential sweep, a shoulder anodic to the main activation peak occurred. However, such a shoulder was not seen in the material that showed fissures or remained unaffected. The current density of the shoulder nearly corresponded to the peak current density of the reactivation peak, indicating that the shoulder occurred due to dissolution of Cr+Mo regions. Also, the peak current density of the shoulder was higher in the case of broken specimens than cracked specimens.

The eddy current (EC) signal amplitudes from various specimens in the as-aged condition (prior to Strauss test) are shown in Fig. 4 and Table 1. It is seen that the overall change in the amplitude among all the specimens was small i.e. about 0.75 V with a maximum scatter of ±0.008 V. This was due to a small change in conductivity/permeability by the depletion of Cr adjacent to grain boundaries which caused local increase in the Ni content that resulted in increased magnetic permeability of the material. Figure 5 and Table 1 show that the overall change in the EC amplitude among all the Strauss-tested specimens was of the order of 8.0 V, which was much higher than that observed for as-aged specimens. This was because of the dissolution of Cr depleted regions and the consequent grain boundary grooving that occurred during Strauss test. Grain boundary grooving causes enhanced perturbation of EC flow which, in turn, leads to increased impedance change i.e. signal amplitude. The fact that unaffected specimens also included those with continuous grain boundary carbide



(a)

(b)

Fig. 3: Double loop EPR curves for type 316 stainless steel that (a) showed cracks, and (b) was broken, in bend tests

Table 1: Bend test, EPR, depth of attack and eddy current testing results at a glance

No.	EPR Results I_r/I_a (%)	EPR Results Q_r/Q_a (%)	Depth of attack (mm)	EC response (Volts)		Category of the specimen (after bend test)
				As-aged specimen	Strauss tested specimen	
1	0.02	0.16	—	0.0	0.0	Not affected
2	0.27	0.18	—	0.012	0.12	Not affected
3	0.25	0.17	—	0.012	0.13	Not affected
4	0.24	0.18	—	0.012	0.12	Not affected
5	0.011	0.17	—	0.012	0.13	Not affected
6	0.011	0.15	—	0.012	0.12	Not affected
7	0.009	0.22	—	0.012	0.12	Not affected
8	0.29	0.04	—	0.015	0.27	Not affected
9	0.89	3.95	—	0.17	0.62	fissures
10	0.92	1.98	—	0.15	0.8	fissures
11	1.38	0.96	—	0.17	0.82	fissures
12	0.77	0.45	—	0.15	0.75	fissures
13	0.52	0.38	—	0.15	0.72	fissures
14	5.6	5.86	75.0	0.21	2.43	cracks
15	12.15	17.86	147	0.30	6.22	cracks
16	5.62	6.18	79.8	0.35	3.18	cracks
17	18.15	20.01	154	0.40	6.5	cracks
18	14.2	26.7	104	0.35	6.4	cracks
19	5.56	12.23	92.1	0.30	4.2	cracks
20	20.87	36.11	103	0.49	6.7	cracks
21	56.8	67.2	308	0.65	7.85	Broken
22	37.6	59.1	190	0.62	7.5	Broken

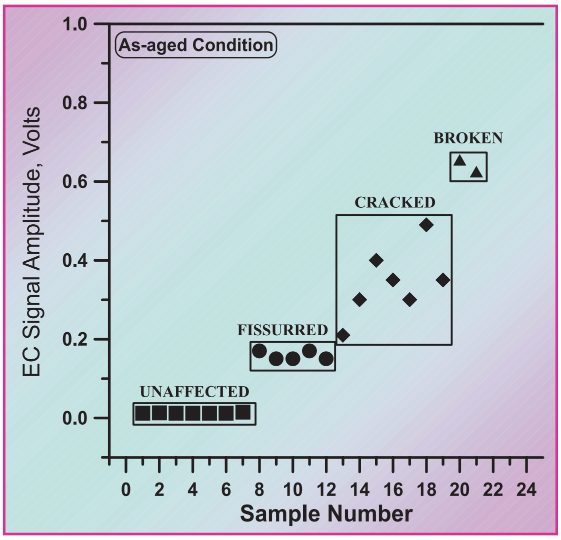


Fig. 4: EC responses from the as-aged condition specimens are in good agreement with the four categories of specimens classified after bend test

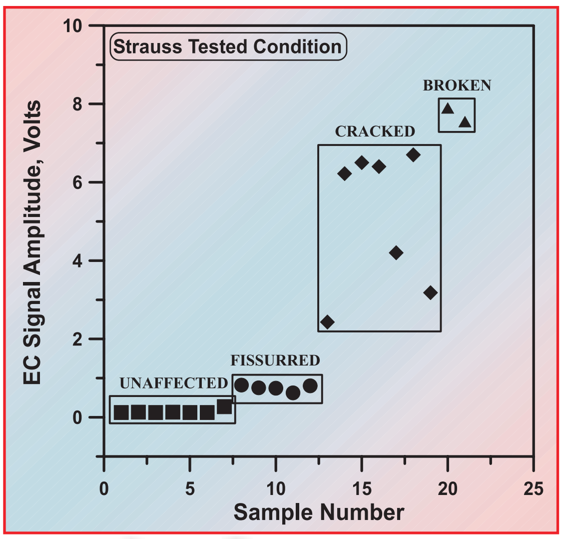


Fig. 5: Comparison of EC responses from the Strauss tested specimens with severity of the damage developed after bend test

precipitation but self-healed indicated that carbide precipitation per se had little or no role in affecting the conductivity/ permeability of the steel.

A very important and potential application arising from the present study is that by knowing the EC signal amplitude for different category specimens, the propensity to and extent of IGC could be assessed without subjecting the specimens to bend test. The impact of this would be felt during monitoring of the SS components in service by providing vital information on the initiation and progress of IGC/IGSCC. Also, ECT could be used as a reliable tool to ensure quality of fabrication against sensitisation. This would help fabricators and the users to guard against sensitisation, particularly in applications where fabrication costs are linked to DOS. However, for this to be feasible, proper optimization of EC test parameters, precise calibration and systematic and reliable measurements are important pre-requisites.

(Reported by: - B.P.C. Rao & H. Shaikh, Non-Destructive Evaluation Division, Corrosion Science and Technology Division, Metallurgy and Materials Group)

Prediction of Chloride Redistribution in Concrete Structure of PFBR

The entry of seawater into the PFBR construction site at Kalpakkam, on December 26, 2004, during Tsunami, entailed a detailed study on the extent of chloride ingression into the concrete that had been laid and its consequences on the subsequently built layers. It was necessary to assess whether the chloride content in the newly built concrete would be below the allowable limit of 0.6 kg/m^3 (as per IS: 456-2000), even after 150 years. The studies included prediction of redistribution profiles of chloride in the concrete structure up to 150 years and an assessment on the reliability of the estimated concentration profiles. These studies were carried at Physical Metallurgy Section in collaboration with Particle Irradiation Facility and Theoretical Studies Section, MSD, with inputs from BHAVINI.

Prediction of chloride concentration in the concrete structure, during its service life:

The problem is represented schematically in Fig.1, where inundation of seawater on the concrete structure of Pour 1 (P1) and Pour 2 (P2) is illustrated.

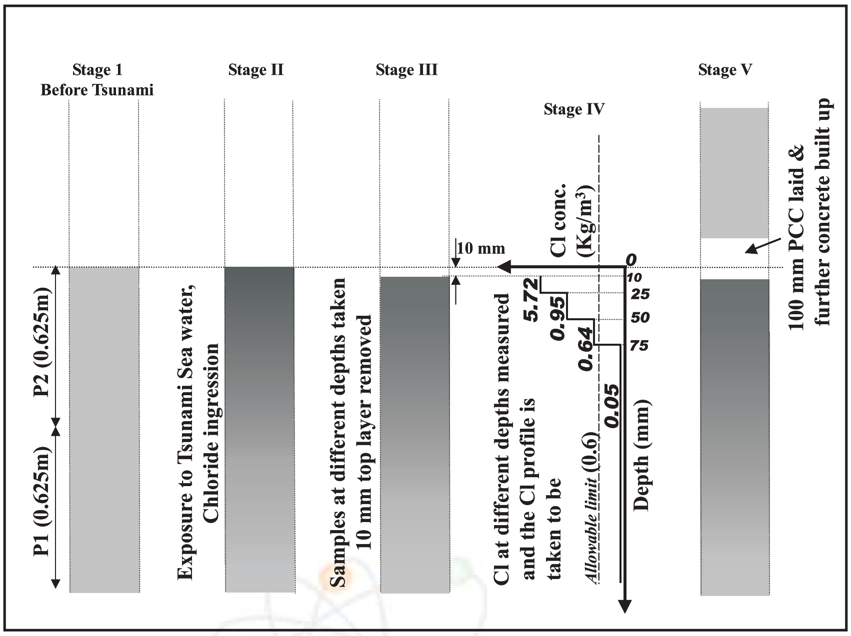


Fig. 1 Schematic Elevation View of a section of the concrete built-up

Chloride concentrations, used in the present study at different depths in P1 and P2, were reported by BHAVINI. The chloride level in the freshly built layers consisting of 100 mm of PCC i.e. concrete with 30% fly ash followed by normal structural concrete (Stage V) was 0.05 kg/ m^3. However, it was necessary to ascertain that an increase, if any, in chloride concentration in the structural concrete due to diffusion from the underlying layers, would be within the permissible limit even after 150 years.

The redistribution of chloride within the structure occurs essentially by a diffusion process. One-dimensional diffusion equations were set up with appropriate initial concentrations and boundary conditions, and solved using Numerical methods to obtain the chloride concentration at the required distance and time. The inputs required for the above calculation namely the initial concentrations of chloride and diffusion coefficients of chloride in concrete (D_c) and fly ash containing concrete (D_{PCC}) were taken from the BHAVINI report and literature on similar type concrete respectively. The predicted chloride concentrations are shown in Fig. 2. It is seen that the chloride concentration is always well below the allowable limit on the surface of fly ash concrete (Fig. 2(a)) and also in the entire concrete structure even after 150 years (Fig. 2(b)).

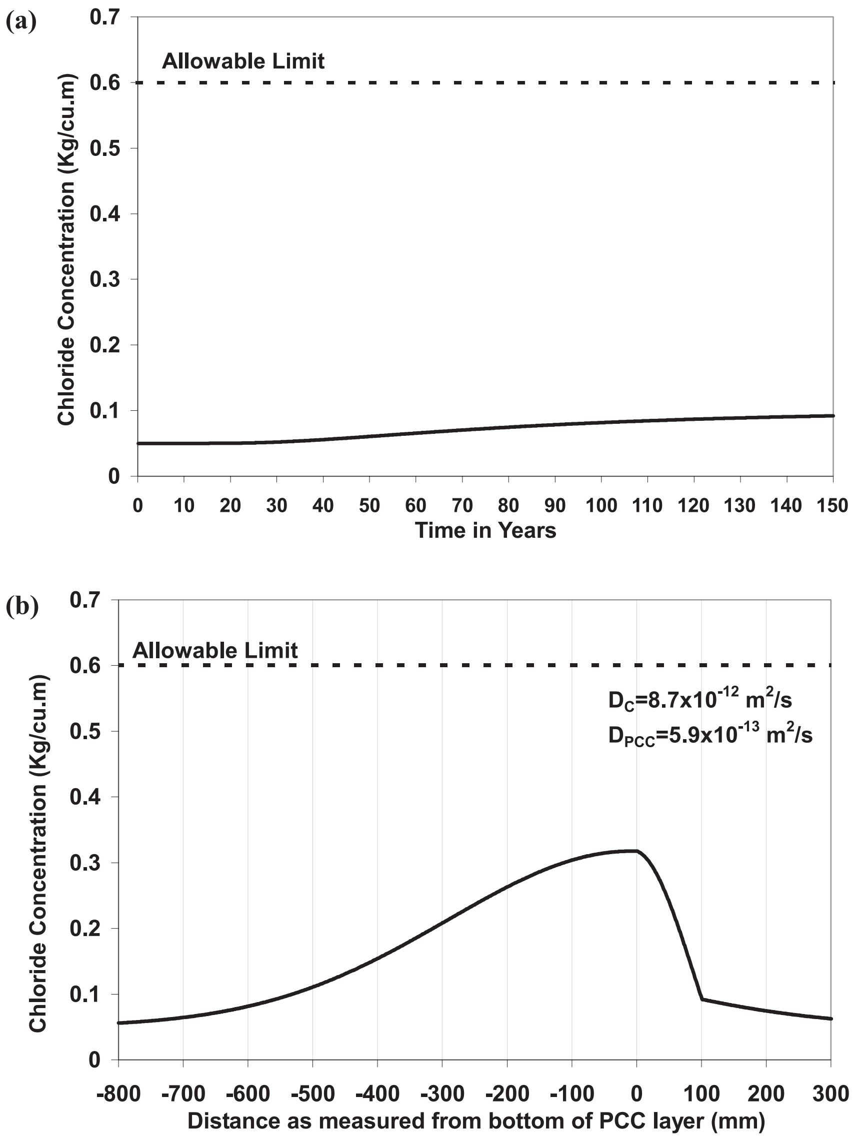


Fig. 2. Chloride Concentration profile in concrete as a function of (a) time at the surface of PCC (b) depth after service life of 150 years

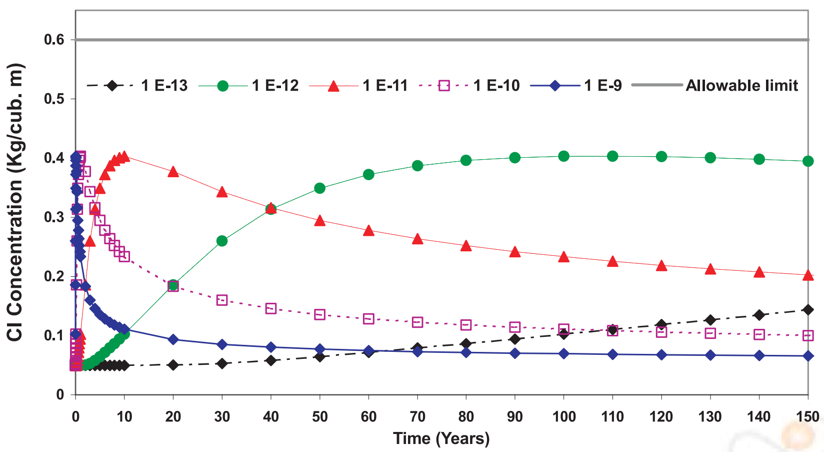


Fig. 3. Calculated Chloride Concentration Profiles as a function of time at surface of PCC (100mm above P2) for different 'D' values

Reliability assessment of the concentration profiles:

The concentration profile in Fig. 2 was evaluated using diffusion coefficient (D) values from literature. Hence, validation of the selection of D values and examination of the sensitivity of the concentration profiles to possible variations in D were essential. An extensive compilation of reported D values was examined. The D values were found to be in the range of 10^{-14} to 10^{-11} m^2/sec, representing various types of concrete, exposure conditions, and testing methods. The concentration profiles evaluated by analytical method, as a function of time (up to 150 years) at a distance of 100mm above P2 using a range of D values are shown in Fig 3. It can be seen that the concentration always remained below the permissible level of 0.6 Kg/m^3, for even a 'D' value as high as 10^{-9} m^2/sec, which is two orders of magnitude higher than the highest value reported in literature and can be considered to represent an extreme situation.

Factors leading to high 'D', representing an extreme scenario:

A concrete block (150mm cube) that was mixed using normal water but was subsequently cured in seawater for 20 days was obtained from BHAVINI. Microstructural and microchemical details were obtained from specimen from this block using an Environmental Scanning Electron Microscope attached with an X-ray Energy Dispersive Analyzer.

The block exhibited a typical microstructure (Fig. 4(a)) consisting of an inhomogeneous dispersion of aggregates of different shapes and sizes, the binding medium of hydrated cement paste and an interface (of ~ 2-5 μm) between cement and aggregates. Micro chemical analysis of the specimen showed chloride to be preferentially present in the cement phase. During curing, water reacts with tricalcium silicate mineral to form the porous hardened cement paste and chloride

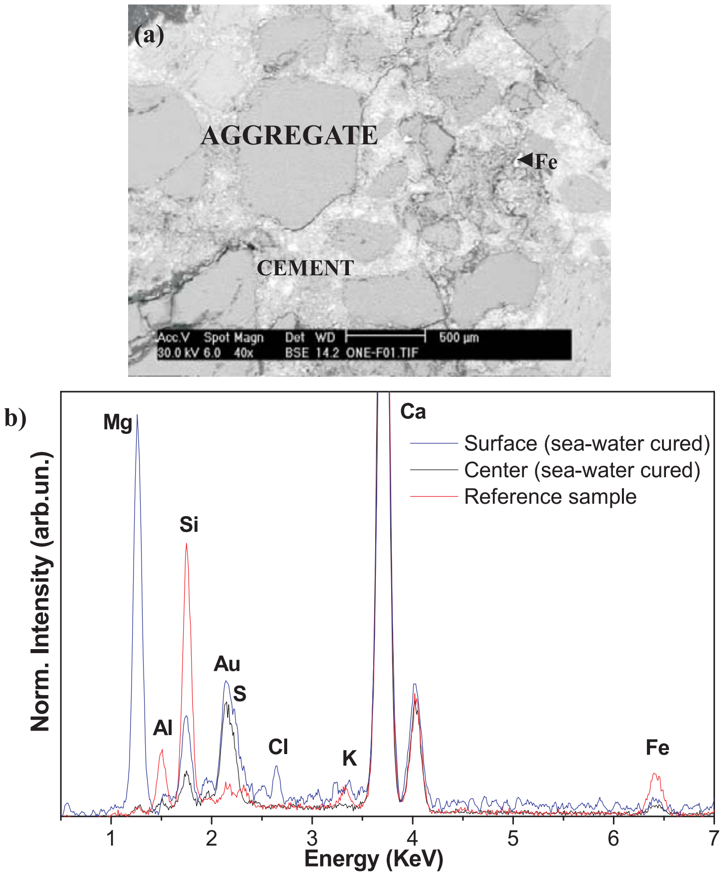


Fig. 4 (a) Microstructure of concrete cured in seawater (b) EDS spectra for seawater cured concrete surface vs. center compared with reference cured in normal water.

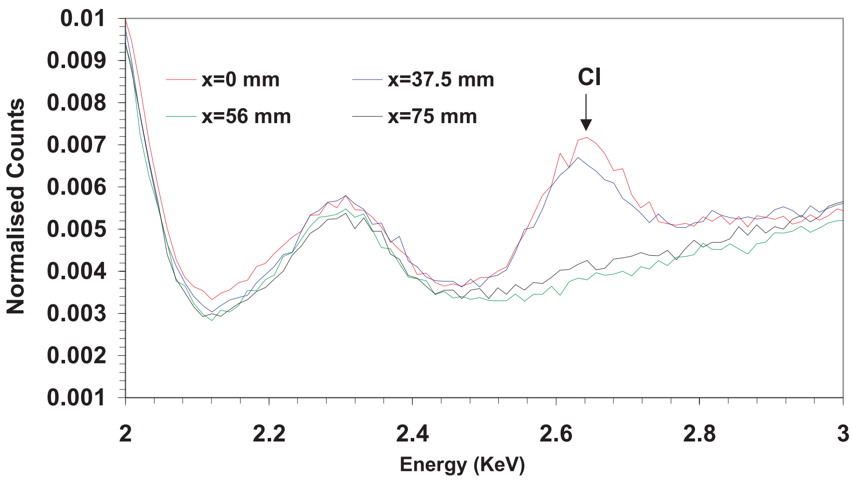


Fig. 5 Chloride profile by PIXE Analysis of specimen from different depths of the concrete block cured in sea water (x=depth from surface).

species exist predominantly within the pores of the cement phase. Figure 4(b) shows an EDS spectrum from the cement region of the specimen. The intensity of Chlorine-Kα peak at the surface of the seawater cured concrete is higher than that of the normal water cured concrete, while the peak could not be detected at a depth of about 75mm in the seawater cured block.

Chloride concentration measured by Proton Induced X-ray Emission (PIXE) technique on specimen from different depths of the seawater cured block is shown in Figure 5. It is seen that the net intensity of chlorine at the surface of the block and up to a distance of 35-40 mm is higher than that at larger distances or at the center of the 150mm block. The D value obtained by fitting the above chloride concentration profile is ~1.8 x 10^{-9} m^2/s, which is higher than values reported for cured concrete ~ 10^{-13}-10^{-11} m^2/s.

The above experiment shows that high value of D was obtained in a concrete exposed to seawater during initial stages of curing. The high rate of chloride diffusion in seawater cured concrete is due to the undeveloped pore system in the wet concrete, in the initial stages of hydration of cement. This diffusion process, in principle could have proceeded indefinitely, but for the simultaneous hydration process of cement, which hardens the concrete introducing an impermeable, tighter pore system arresting further ingress. However, in cured concrete structures such high rates of diffusion are not expected during service. Calculated concentration profiles in Fig. 3 have also shown that the chloride concentration is below the allowable limit up to 150 years for value of D as high as 10^{-9} m^2/sec.

These studies lead to the conclusion that chloride content on the surface of the PCC layer would always be below the allowable limit.

(Reported by: T.Karthikeyan, S.Saroja and M. Vijayalakshmi, Physical Metallurgy Section, Materials Characterisation Group)

Development of Cross Wire Type Leak Detector

Double ended guillotine rupture of Steam Generator (SG) tube resulting in large amount of water leaking into sodium is a design basis event for fast breeder reactors. Hydrogen generated in the process, sets up a pressure wave and rupture discs are provided at the entry and exit sodium headers, to relieve the pressures into a confined storage tank along with reaction products. The failure of the rupture disc is generally detected by a spark plug type leak detector on the downstream which then initiates the other safety actions on the plant. It was desired to improve the reliability of detection of rupture disc failure by a diverse means. Towards this a Cross Wire type Leak Detector (CWLD) has been developed and tested at the laboratories of the Fast Reactor Technology Group.

CWLD comprises of three numbers of stainless steel foils located in cross wire fashion placed downstream of the rupture disc as shown in Fig.1. V grooves have been provided on the foils to give a minimum breaking pressure. These foils have to break when sodium and its reaction products passes over them.

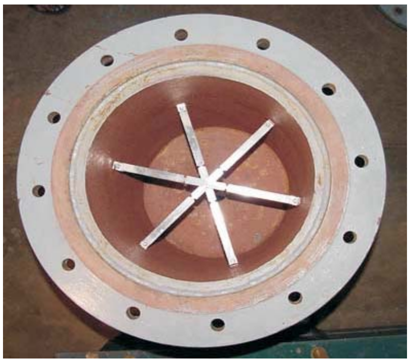


Fig 1 a CWLD foils

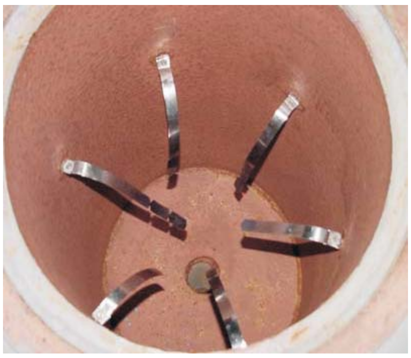


Fig 1 b Foils after breaking

All the three foils are insulated from each other and are placed in such a way that there is no physical contact between them. The resistance of the foil is continuously measured using the electronics. In case of a rupture disc burst, the high pressure breaks the foils resulting in sudden jump in resistance. The electronics senses this change in resistance which gives alarm signal indicating that sodium water reaction has taken place in the steam generator. This type of leak detection technique is a unique attempt for SG's of FBR's.

The electronics for the leak detection system comprises of individual circuits for each of the foils. The leak detector modules are supplied with constant voltage through the foils. The comparator in the circuit compares the output from each foil to the fixed set point and 2/3 logic determines the bursting of rupture disc. The development of CWLD involves optimizing the thickness of the foils and determination of breaking time for snapping technique.

The mechanical design and thickness of the foils were optimized based on a large number of tests in water. Fig. 2 shows the test set up. The tests were carried out at ambient temperature in the hydraulic loop of Fast Reactor Technology Group. Mild steel pipe of OD 406 mm was used for set up. In this set up, all the three foils were installed inside the pipe at a uniform gap of 10 mm and at 60° apart so that all the foils had no physical contact with respect to each other. To electrically insulate each of the foil from the pipe, two MICO spark plugs were installed in the pipe. The MICO spark plugs were installed in the pipe with the help of sleeves. A holder, which is welded to the central electrode of the spark plug, was used to hold the foil. A Perspex window was provided at the top of the flange to see the foils after impact of water. For testing, foils were kept at a distance of 140 mm from the point of application of hydraulic pressure. Electronic connections were given to the terminals of the spark plug.

The cross-wires were tested for sudden flow. Water was admitted into the test setup by sudden opening and closing of a ball valve. This pressurized water makes impact on these foils causing them to snap. The pressure required for snapping was recorded. A dynamic pressure transducer was installed to measure the pressure of water at the time of opening of the ball valve. Testing of foils was also

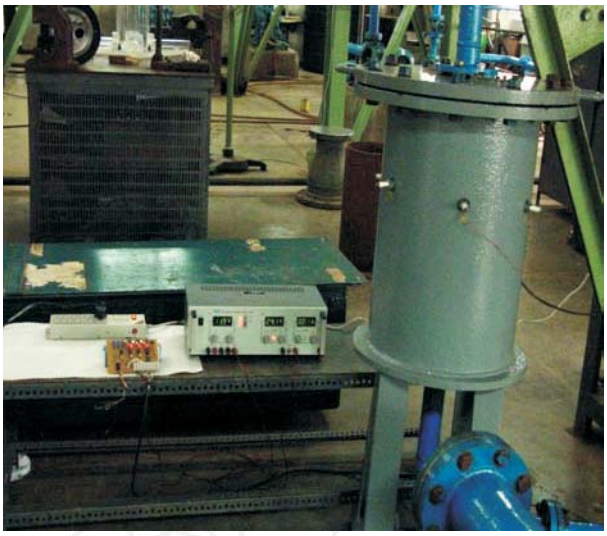


Fig.2 Test setup with electronics

carried out by varying the depth of the V-notch grooves. The depth of the grooves were varied from 5mm to 6mm keeping the width & thickness of the foil and V-notch angle of 60° constant. The foils had been tested a number of times to check the reproducibility of the breaking pressure (Fig 3).and it was found that the foils snapped between a pressure of 1.25 kg/cm^2 (0.125 Mpa) and 2.8 kg/cm^2 (0.28 Mpa). It corresponds to a velocity of 2 m/s in the test set up. The minimum pressure and velocity of reaction products in PFBR is 0.37 Mpa and 2 m/s respectively.

The breaking pressure required for snapping the foils depend on the pre-tension in the foil. A higher pre-tension imparted to the foils while tightening causes the foils to snap at lower pressures. If installation of foils are not proper it can also lead to improper breaking pressures. Due to the impact loading the foils which are not installed properly get deflected and the breaking pressure is found to be larger.

With these experiments, the CWLD for PFBR steam generator has been successfully tested. The specification of the CWLD to be employed in PFBR has been finalized as follows:

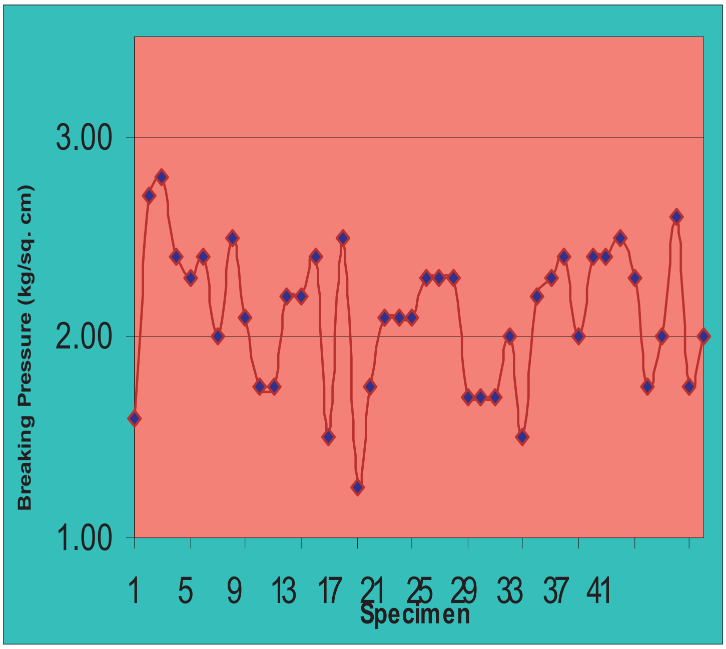


Fig. 3 Breaking pressure at different trials

SS foil specification

Length of foil	:	338 mm
Width of foil	:	15mm
Thickness	:	50 micron
Depth of V notch (i.e. 3 mm of foil width between two opposite V-notches and include angle of 60°)	:	6 mm

(Reported by Sudhir T.Ninawe and P.L. Valliappan, Components and Instrumentation Development Division)

CONFERENCE ANNOUNCEMENTS

Twenty years of FBTR Operation

FBTR went critical on 18th October 1985 and will be completing twenty years of operation on 18th October 2005. Being the forerunner to the second stage of our nuclear programme, it is proposed to celebrate this event in a fitting way. By that time, the Mark-I fuel would also have crossed a record value of 150 GWd/t, the highest for any driver fuel.

To formally mark the start of the celebrations, a seminar in Tamil will be held on 18th October 2005, with participation by the employees of FBTR on the significant technical jobs executed by them. On 23rd October 2005, there will be an 'open-house' for the family members of FBTR employees.

This will be followed by a get-together of all unit heads of DAE, Ex-chairmen, ex-directors of IGCAR and retired officers / employees, who contributed to FBTR both at the project and operational stages. This is presently slated for February 2006.

Subsequently, it is proposed to have a two-day technical seminar covering the operational history and system performance of FBTR. The proceedings would be subsequently compiled and released as CD & book, to serve as a landmark exercise in knowledge management. It is also proposed to bring out a documentary film on FBTR, and a book giving the reminiscences of retired senior officers of the department.

(Reactor Operation & Maintenance Group)

Parallel computing facility established at RSD using a distributed memory Linux Cluster

A cost-effective high performance scalable Linux cluster computing system has been successfully commissioned at RSD for implementing a parallel real time atmospheric dispersion forecast model. The system comprises of off-the-shelf physical elements and open source software (Fig.1, Table 1). In the present configuration, hyper-threading is enabled in duel Xeon processors (each has 4 logical processors) so that a the 8 + 1 node cluster could provide up to 36 logical processors for executing the Distributed Memory program.

Fig.1 Gigabit Ethernet Linux Cluster

CLUSTER NETWORK SPECIFICATION	
Rack mounted Servers	: 8 no.
Desktop Server	: 1 No.
Specification for each:	
Processor	: Duel Intel Xeon
Cache memory	: 1MB L2 per processor
Bus Speed	: 800 MHz
RAM	:2GB ECC
LNA Interface	: 2 Intel Pro/1000
HDD	: 3 X 36 GB Ultra 10k RPM Drive
Form factor	: 5 U rack mounting
Ethernet Network Switch: 16 port 10/100/1000 MBPS, RJ45 ports & CAT 6 UTP connectivity	
KVM Switch 16 port , supporting Video quality 1920X1440 MAX, form factor1U	
UPS 6 KVA	
42U Server Rack: 2 No.s	

Table 1. System Specification

In order to estimate the cluster performance, the system speedup is tested with a MMS atmospheric model as well as a (transpose) benchmark program; MM5 is based on Monte Carlo algorithm and matrix multiplication using OCTAVE Parallel programming library. Preliminary result on system speed up is shown in Fig.2.

Features of the Cluster at RSD

- Debian LINUX with precompiled software bundles for easy installation
- OS installed using single CD independently in all computers
- Software KNOPPIX verity chosen for latest and universal hardware detection as well as scientific computing software modules
- MPICH installed for message passing interface for parallel programs
- Password-less login across the nodes enabled through SSH for each user
- Commercial Split AC used for thermal management
- System in continuous operation

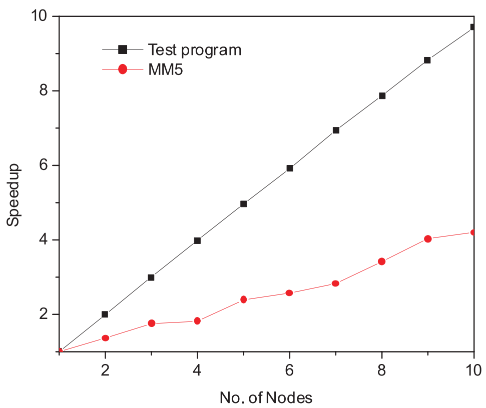


Fig.2 System speedup diagram

(Reported by N.V. Muralidharan, C.V.Srinivas & R.Venkatesan, Radiological Safety Division)

Modelling the Electrorefining Process

Suddhasattwa Ghosh
(DOB- 30.09.1980) did his M.Sc(Chemistry) from Rani Durgavati Vishwavidyalaya, Jabalpur, Madhya Pradesh in 2003. He is from the 47th Batch of BARC Training school and joined IGCAR in September 2004 as Scientific Officer (SO/C).

Pyrochemical reprocessing refers to high temperature chemical processing of the spent fuel for separating the valuable fuel constituents, U and Pu, from the fission products for recycling. Molten salt electrorefining, an important pyrochemical reprocessing method ideally suited for metallic fuels, exploits the differences in the thermodynamic stabilities of the chlorides of fuel materials and fission products for achieving the separation. In this process, carried out at 773 K., the spent metallic fuel is immersed in a molten chloride electrolyte and U and Pu are selectively electrotransported to cathodes whereas the noble fission products are left at the anode and the rare earth fission products are transferred to the electrolyte. A solid cathode is used for the electrotransport of Uranium alone which is useful for processing the blanket and a liquid cadmium cathode for electrotransporting U and Pu together which is employed for processing the driver fuel containing higher amounts of Pu.The selective deposition of U on a solid cathode is enabled by the higher Gibbs energy of formation of its chloride than those of the chlorides of Pu and minor actinides. At the liquid cadmium cathode, however, the codeposition is facilitated by the lower activity coefficient of Pu in cadmium compared to that of U.

The advantage of this process is that it uses molten salt as electrolyte that is more compatible with highly radioactive short cooled FBR spent fuels than the organic solvents (tri-butyl phosphate) used in PUREX process that would undergo radiolytic degradation. The critical mass of fissile material in the salt is less restrictive compared to that in aqueous solutions. Minor actinides, such as Np, Am and Cm are expected to be deposited along with U and Pu, get recycled and thus be transmuted in FBR's.

Modelling the electrorefining process

The importance of modeling of a process is three fold- firstly, to verify the experimental conditions; secondly, to see the behaviour of the system under conditions that may not be achievable in the laboratory or plant and thirdly, to optimize the parameters to get maximum possible output from the system under study which will be useful for scaling up the process to industrial scale. The ability to predict the process outcome using the modelling saves a lot of time and energy to be spent in carrying out the process at high temperatures of the order of 773 K under high purity inert atmosphere required for handling molten salts and the actinide metals.

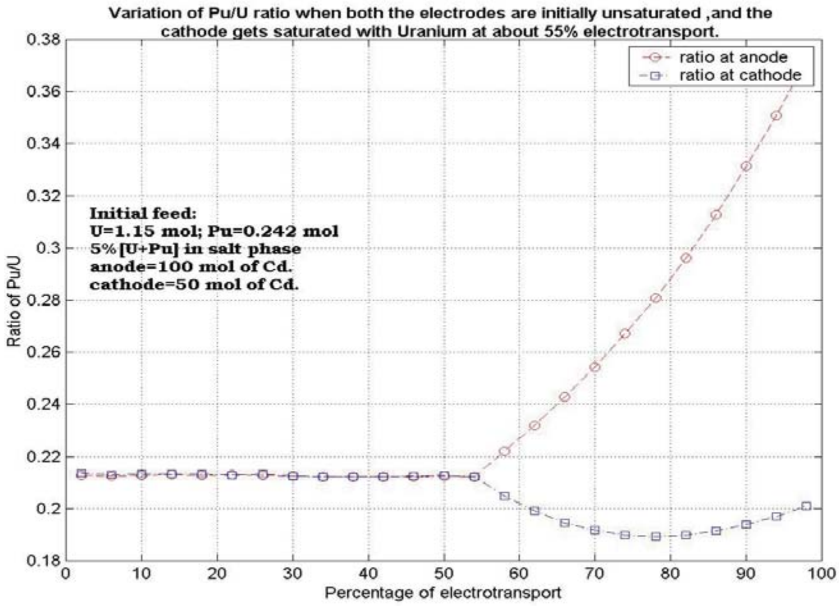
Several research groups have developed numerical codes for the molten salt electrorefining process. Based on the thermodynamic model of Johnson, Ackerman of ANL developed the code called PYRO that was written in PASCAL and was based on thermodynamic equilibrium considerations. Research groups at CRIEPI, Japan have developed TRAIL and PALEO codes based on a diffusion model. These models work very well at low current densities but the predictions based on these models degrade at higher current densities, when kinetic factors become important. Recently, Ahluwalia et al. have developed the code GPEC to determine the anode and cathode current structure and the time dependent V-I curves for different modes of electrorefiner operation.

The thermodynamic model

The model is based on the thermodynamic equilibria that can be envisaged between pairs of metals in the spent metal fuel and their chlorides in the salt . For example, the equilibrium between uranium and plutonium will be

UCl_3 (salt) +Pu(Cd) $\rightarrow$ $PuCl_3$(salt)+ U(Cd)

The activity based equilibrium constant K_{eq} governs the distribution of the metals between the liquid metal phase and the salt phase. Depending on the concentrations of U and Pu in the initial feed to the electrorefining cell, the liquid cadmium anode (LCA) may be (a). Unsaturated with U and Pu, (b). Saturated with U but unsaturated with Pu, (c). Saturated with Pu but unsaturated with U, (d). Saturated with both U and Pu. With gradual electrotransport of the fuel material from the LCA to the the LCC(liquid cadmium cathode), the latter may get saturated with either U or Pu or with both U and Pu. One can envisage 16 possible combinations of the anode and cathode. The simulation of the electrorefiner



operation with 16 possible cases has been completed using MATLAB. The computations involve setting up of simultaneous algebraic non linear equations and systems of linear equations of sparse matrices that are solved using standard techniques available in the literature. Our computations show that the rates at which U and Pu migrate to the LCC depend on their respective saturation levels at the LCA and LCC. For example, the following plot represents the conditions when both the electrodes are unsaturated with both U and Pu to start with and then cathode gets saturated with U after a certain percentage of electrotransport.

When both the electrodes are unsaturated, the rates of transport of U and Pu are equal as well as the Pu/U ratios at both the electrodes. After about 55 % transfer Cd cathode gets saturated with U. The rate of transport for U increases, as a result of which the Pu/U ratio at the cathode decreases and that at the anode increases. The effect of the electromotive force at the anode and cathode has also been studied as a function of electrotransport. The simulation studies would need to be validated by experiments that would be carried out at high temperature involving handling of active materials in argon atmosphere glove boxes.

The present model will be extended to three-component systems with which the transport behaviour of the three components of U-Pu-Zr alloy fuels during electrorefining can be studied. Irradiation of test fuel pins with metallic fuels and their reprocessing will form part of development programme for metallic fuels. The plutonium concentration of the U-Pu-Zr fuel for the test fuel pins in FBTR will be as high as 50 wt.% and there is no information in literature on the behaviour of such high Pu fuels. Our modelling will be used for predicting the behaviour of these test fuels during reprocessing which will be verified during the actual processing of these pins.

The diffusion theory model

The model based on diffusion layer theory is a better tool for predicting the behaviour of the electrorefining process than the thermodynamic model. This is because the latter does not incorporate the various electrokinetic factors that might affect the overall electrorefiner operation. It takes into account the diffusion, electromigration, Stern Geary equation and Butler Volmer kinetics at the electrode interfaces. It will involve setting up of coupled nonlinear partial differential equations that would be converted to a system of ordinary differential equations. Hence the model can be applied to study the effect of various physical parameters on the performance of the electrochemical process such as diffusion layer thickness, electrode geometry, diffusion current and the applied composition. It has been shown that the polarization curves generated using these models are in agreement with the experimental results. The development of codes based on the diffusion model has been initiated in our laboratory.

A laboratory scale argon atmosphere facility in our laboratory is used to carry out studies on the molten salt electrorefining process on U alloys and now, a demonstration facility for engineering scale process studies is being set up. The results of the computations would be used for optimizing the design parameters of the electrorefining cell and they will be validated with the experimental results.

(Suddhasattwa Ghosh and Colleagues
Fuel Chemistry Division,
Chemistry Group)

"...The emphasis throughout has been on developing know-how indigenously and on growing people, able to tackle the tasks, which lie ahead..."

- Homi. J. Bhabha

Structural Integrity of Core Catcher under Core Disruptive Accident Loading

In the 500 MWe sodium cooled pool type fast breeder reactor (PFBR) the entire primary circuit including core is housed inside the main vessel with a top shield. The grid plate supports the core subassemblies (CSA), which is in turn supported by the core support structure (CSS). The CSS is attached with the main vessel bottom at the triple point through a support shell. The safety of reactor is ensured in many ways by following defense-in-depth approach. Accordingly, even though core disruptive accident (CDA) is a very low probability event, it is investigated in detail including its consequences. Subsequent to CDA, the method of post-accident heat removal is also well planned. In order to mitigate the consequences of core melt down, the core catcher structure is placed below CSS, which gets supports from CSS support shell (Fig. 1). The core catcher must collect the core debris, support them and maintain in sub-critical configuration. It must prevent the debris settling on MV and keep the MV temperature within acceptable limits from creep consideration by facilitating sufficient natural convection mode.

The core catcher is basically designed for accommodating the core debris resulting from melting of 7 fuel subassemblies in order to meet the safety criteria. However its structural integrity is investigated for accommodating whole core meltdown condition. The core catcher designed for PFBR consists of a 20 mm thick core catcher plate (CCP), with a flat pan of 6.4 m diameter. A heat shield plate (HSP) is provided to protect the CCP against thermal shocks. Support pins are provided between HSP and CCP to maintain the gap. At the centre, a 500 mm diameter chimney is provided to aid natural convection flow of sodium. The whole assembly is placed over a number of tapered ribs, which are welded to the core catcher support plate.

In the event of a core disruptive accident, a very high pressure will first act on the core catcher, and subsequently the molten core debris will start settling on it. For the structural integrity assessment, a 40° symmetric sector (Fig. 2) along with MV and CSS shell is modeled in CAST 3M, a computer code issued by CEA, France. The CC is first analysed for the transient pressure loading during CDA. The stresses for the reference geometry (Fig. 3a) are found to be high at the support flange to CSS shell junction and support plate knuckle to flange junction. The stresses and deformation on the HSP are also found to be high. To reduce the stresses, the geometry at the junction has been modified. The flange support is changed to skirt support. The support pins between CCP and HSP are shifted radially outward. Analysis has been carried out with modified geometry (Fig. 3b). The stresses (Fig. 4) for this case were found

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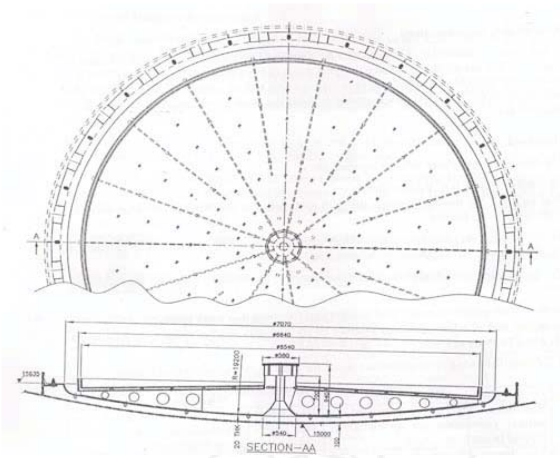

Fig. 1 Schematic of core catcher

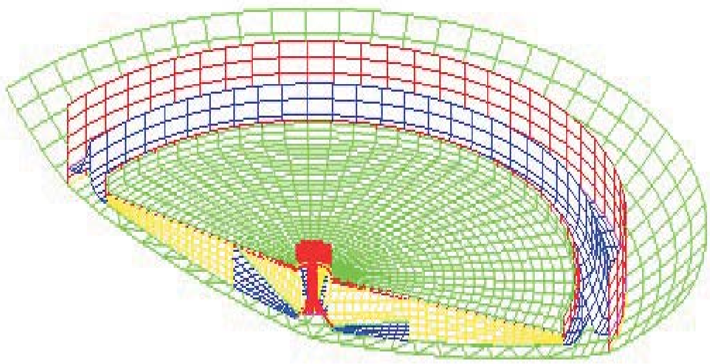

Fig. 2 FEM mesh for the analysis

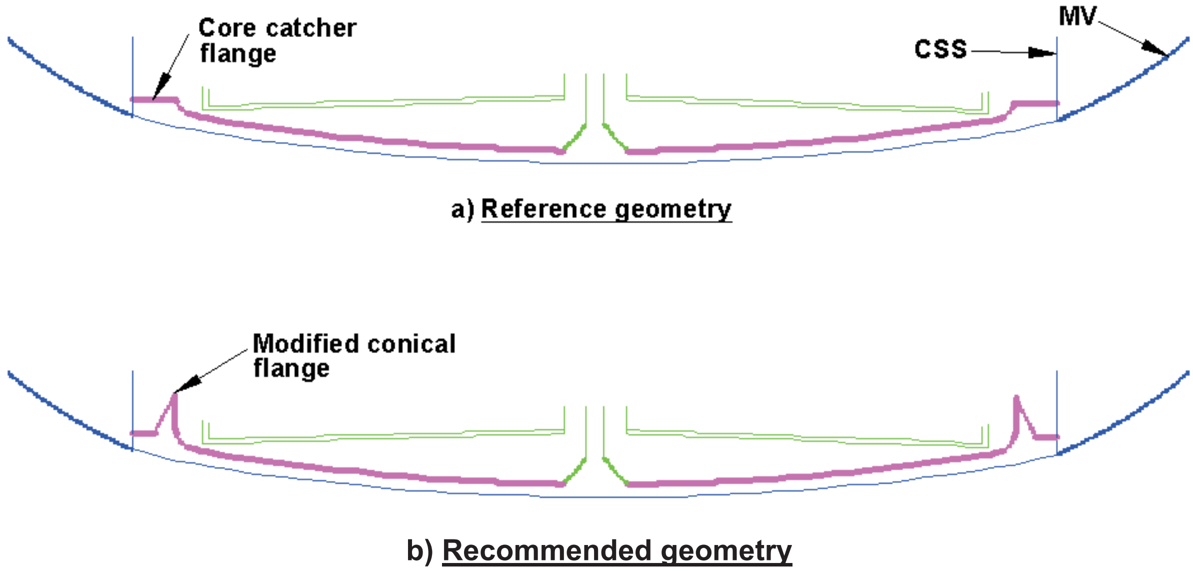

Fig. 3 Recommended geometrical shape of core catcher

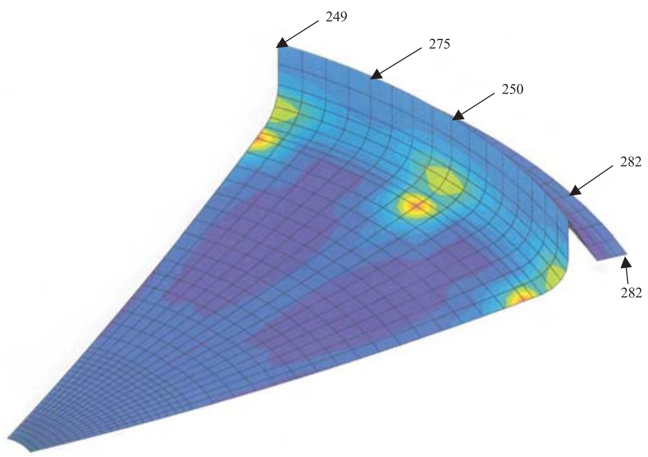

Fig. 4 Von–Mises stresses on CC junction for modified geometry

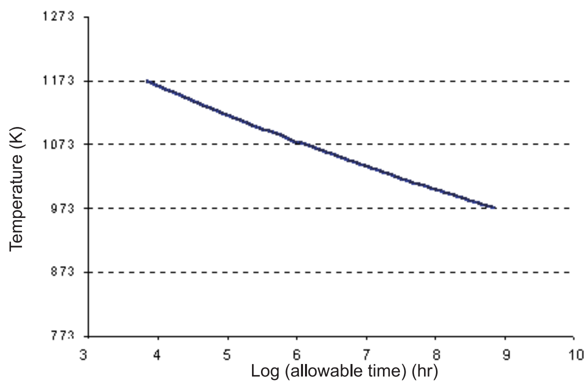

Fig. 5 Effective Temperature Vs Allowable Time

to be within the limits of RCC MR 2002, recommended design code for PFBR.

Subsequently, the structural integrity was assessed for post-accident heat removal phase with respect to creep damage for the steady load of molten debris of the whole core at high temperature. Based on the apportioned creep damage of 0.4 for category 4 events, the variation of effective temperature at which CC can be subjected to, is plotted against allowable time (Fig. 5). Based on the apportioned creep damage of 0.4 for category 4 events, the allowable time at 1173 K is 308 days, which is well within the acceptable limit.

(Bhuwan Chandra Sati and Colleagues, Mechanics & Hydraulics Division, Reactor Engineering Group)

HIGHLIGHTS OF THE CONFERENCE ON

Recent Advances in Information Technology

READIT-2005

IGCAR, July 14-15, 2005

Scientific Information Resources Division (SIRD), IGCAR and Madras Library Association – Kalpakkam Chapter (MALA-KC) have been conducting, for about a decade, a series of conferences on "REcent ADvances in Information Technology (READIT)" and the conference for 2005 was held at IGCAR during July 14-15, 2005. The main theme of the conference was "Digital Libraries to Knowledge systems", with sub-topics on Facets of Digital Library, Information Management, Knowledge Management, Knowledge Sharing Techniques and Library the Gateway. The conference was preceded by a one-day tutorial on "Advanced Methods & Technologies for Content Management" and "Application of Open Source Solutions for Digital Libraries" on July 13, 2005.

At the inaugural session on 14th July, Shri P. Swaminathan, Director, Electronics & Instrumentation Group, IGCAR welcomed the gathering. Dr. Baldev Raj, Director, IGCAR gave the presidential address and illustrated the origins of library services and its evolution in the centre paying rich tributes to the pioneering work of Dr. G. Venkataraman in this regard. He stressed the need for "sharing and synergism of knowledge with proper coherence". The inaugural address was delivered by Dr. T. Ramasami, Director, CLRI, who emphasised the importance of digital libraries and knowledge updating. The Keynote address was given by Prof. S. P. Thyagarajan, Vice-Chancellor, University of Madras, who delivered a lucid presentation on e-learning. Shri M. Somasekharan, Head, SIRD, IGCAR proposed the vote of thanks.

The conference encompassed six technical sessions including invited and oral presentations. The themes for these sessions were "Facets of Digital Library", Information Management", Knowledge Management", "Knowledge Sharing Techniques" and "Library the Gate Way". The technical session on "Facets of Digital Library" commenced with an infectious and enthusiastic invited talk by Dr. S. Venkadesan, Librarian, JRD Tata Library, IISC, Bangalore, elucidating various facets of digital library in terms of its contents, organisation, services, technology and people.

The topic of the second session was "Information Management". Dr. Nargund, BARC, Mysore presented a very informative talk on "Web Resources for Chemical Safety Information"

The third session comprised of commercial presentations by Wiley Interscience, Libsys Corporation, Access Sciences, IOP and Springer-Verlag.

The fourth session held on the forenoon of 15th July was on "Knowledge Management" wherein Shri P.C. Barua enlightened the participants on the importance of "Human / Intellectual Capital / resources" and how digital library should pave way for its betterment. The fifth session on "Knowledge Sharing Techniques" commenced with two invited talks; the first by Dr. Jagdish Arora, Chief Librarian, IIT, Delhi on " Knowledge Sharing Tools & Techniques" wherein he underlined the importance of various stages such as Data to Information to Knowledge to Wisdom. The sixth session was on "Library the Gateway". In this, Shri M. Somasekharan, Head, SIRD spoke on "Patrons Technology & the Library". He emphasized the importance of technological updates, Digital Library for library patrons, evolution of library and the role played by technology and the patrons in this, benefits steps / philosophy behind Digital Library and Model Library – IGCAR.

In the valedictory function, at the end of two day conference, Shri M. Rajan, Director, Safety Group, IGCAR welcomed the participants. The Presidential address was given by Dr. Baldev Raj, Director, IGCAR and Dr. G. Amarendra, IGCAR, presented the conference summary. The valedictory note was given by Prof. S. Narayanan, Dean, Academic Research, IIT, Madras. Shri M. Somasekharan, Head, SIRD, IGCAR proposed the vote of thanks.

The conference in all was very enriching, informative and covered a variety of topics in current trends in information technology. It brought together the best brains in the country for addressing the latest trends in library sciences viz. the era of digital libraries.

(M. Somasekharan, SIRD)

MEDIMEET & PARAMEDICS MEET 2005

This year Medimeet 2005 was conducted on 29th and 30th April 2005 at the SRI Convention Centre at Anupuram. This was the seventh in a series of medical seminars conducted by the medical fraternity of DAE hospitals all over India. The tradition evolved with the first Medimeet held at BARC, Mumbai in 1993. Medimeets are unique in that they involve interaction between specialists of all fields. Unlike the current trend of conferences for doctors belonging to a single specialty, Medimeet brings together doctors from various fields and from our sister concerns all over India.

To cater to this medical medley the lectures for the conference were carefully chosen to appeal to one and all. Eminent professors of international repute consented to grace the occasion.

The conference was inaugurated by Director, Dr. Baldev Raj whose wisdom and guidance kept up the zest and zeal of the organizers throughout the conference. Shri Prabhat Kumar, Project Director, BHAVINI, Shri S. Basu, Director, BARCF, Mr. S. Krishnamurthy, Station Director, MAPS and Mr. P. Swaminathan, Chairman, HMC also graced the occasion with their presence, support and good will.

The conference began with a guest lecture by Dr. P.T.V. Nair, Head, Medical Division, BARC, Mumbai, who spoke on risk factors in heart disease. Following this illuminating talk was an allied one by Dr. Thanikachalam, Head of the Department of Cardiology, SRMC, and the recipient of Dr. B.C. Roy award 2004, that gave an all pervasive insight on unstable angina and its management. One of the highlights of the day was the lecture by Dr. Usha Sriram, endocrinologist par excellence, who gave new meaning to the term menopause with her academic extravaganza.

Dr. Hariharan, Head of Department of Endocrinology, KMC, Chennai also took the participants to new realms of modern medicine in the management of diabetes mellitus.

On the second day, Dr. Jayanthini, eminent professor of Psychiatry spoke on the common but commonly ignored problem of stress in women. Dr. J. Balavenkatasubramaniam stalwart anesthesiologist from Coimbatore gave a much needed overview of management of trauma victims.

Dr. J.S. Rajkumar, a well known gastroernterologist from Chennai spoke on Abdominal pain. This was followed by another very relevant talk on consumer protection law with reference to doctors, by Dr. Cheran, Professor, Stanley Medical College, Chennai. There were also several presentations by the doctors of various DAE Units, each offering a veritable feast to the audience. There were about 80 delegates in all and the deliberations of the conference provoked much discussion and interaction between the doctors.

Following the above meet, a Paramedics Meet for the staff of DAE hospital was conducted at SRI Convention Centre, Anupuram on 23rd July 2005. Shri P. Swaminathan, Director, EIG, IGCAR and Chairman, Hospital Management Committee inaugurated the programme. Nursing supervisors, nurses, nursing assistants, lab technologists, pharmacists, radiographers and ambulance attendants presented papers on the occasion. Guest lectures by Shri Ilavarasan, Professor of Pharmacology, Dr.C.L. Baid Metha College of Pharmacy Chennai, on Diabetes and Hypertension; Smt.Uma Mageswari, Nursing Supervisor, Sri Ramachandra Medical College on Hospital Infection Control; Shri P.Subramanian, Sanitary Supervisor, GSO, Kalpakkam on Environmental Sanitation were the other highlights of the meet that concluded with a vote of thanks by Smt.M. Lakshmikanthamma, Assistant Matron, DAE Hospital.

(Dr. A. Vijaya, DAE Hospital)

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5^{th} Quality Circle Awareness Day-2005

Quality Circle (QC) Awareness Day programme is being conducted every year at IGCAR in order to propagate the message about the benefits that will accrue among the work force and also for the orgainisation. This year, with the formation of Apex committee for Quality Circles and introduction of Quality circles by more groups, the awareness day programme was conducted for two days on 6^{th} and 8^{th} September 2005. Because of the relevance of QC for every one, various professional bodies in Kalpakkam participated in arranging the programme. The programme was inaugurated by Dr. Baldev Raj, Director, IGCAR & GSO. Shri M.R.Ranganathan, Head, Marketing of SRM Technologies, Chennai delivered the keynote address on “Institutional support and motivation for growth of QC movement”. Thirteen Quality Circles from IGCAR, schools, hospital and GSO presented the case studies. In addition to the participants, members of the newly formed QCs and personnel from other groups numbering around 200 attended the programme. Professional judges from Chennai assessed the case studies presented and also gave valuable guidance to the QC members and motivated them. The enthusiasm shown by all the participants were very gratifying and this helped personnel from other divisions come forward to form QCs.

(K. Ravishankar and V. Venugopal)
Organising committee- QCAD-2005

Awards & Honours

Dr. Baldev Raj has been awarded the prestigious Indian Nuclear Soceity (INS) Award for the year 2004. He has been elected President of Indian Institute of Metals. He has also been elected fellow of The Indian National Science Academy (INSA), New Delhi. He has been conferred with a honorary doctorate by Sathyabama University, Chennai for his contributions in the field of Science & Technology of Fast Reactors.

Dr. U. Kamachi Mudali, Corrosion Science & Technology Division (CSTD) was awarded the INS Medal for the year 2004. He has been awarded the prestigious Metallurgist of the year award for 2005 by Ministry of Steels & Mines. He has also been awarded the Homi Bhabha Science & Technology Award for the year 2004.

Dr. K.G.M. Nair, Materials Science Division (MSD) has been selected for the Materials Research Soceity of India (MRSI) Medal Lecture for the year 2006.

Dr. A.K. Arora, MSD has been awarded the Prof. Y.T. Thathachari Memorial Research Award, Mysore for the year 2005 in the area of physical sciences.

Dr P.R.Vasudeva Rao Chairman, Editorial Committee
Members: Dr.G.Amarendra, Shri M.Ganapathy, Dr.K.V.G.Kutty, Dr.Mary Mohankumar, Shri G.Padma Kumar, Dr. B.Purniah, Shri Shekar Kumar, Shri M.Somasekharan, Shri R.Srinivasan, Shri R.V. Subba Rao, Shri K.V.Suresh Kumar.
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