IGC newsletter

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From the Director's Desk

TECHNICAL ARTICLES

New Year Message

It gives me a great pleasure in wishing you and your families a very happy and blissful New Year and a happy Pongal. As we enter the year 2006, we must have dreams, vision and a firm commitment. Before doing so, it is worthwhile to take stock of various challenges faced by us and the progress achieved in various fronts in the Centre for the last one year i.e. during 2005.

The year 2005 has been a testing time for all of us to overcome the emotional and psychological trauma of Tsunami that occurred on December 26, 2004. It is a matter of tribute to the combined strength of all DAE fraternity and in particular the Kalpakkam community to raise to the occasion and participate in the reconstruction of the township. I am pleased to inform you that due to many innovative decisions as well as sustained moral support from our Chairman Dr. Anil Kakodkar, we could tide over the situation and restore normalcy in the township life in a record time. I would like to record my appreciation to all service wings of GSO and IGCAR viz., civil, electrical and telephones as well as Officers and Staff unions, who have extended their full co-operation in the period of crisis. We have taken the opportunity to improve the townships in terms of general outlook, greenery and amenities. I am happy to mention that normal housing allotment has also been resumed. We are taking urgent steps to build more houses under various categories in Anupuram township. We have erected a memorial and created a park in Kalpakkam township on December 26, 2005, as a tribute to the precious lives lost during this natural calamity.

Fast Breeder Test Reactor (FBTR), the flag-ship of the Centre, has been operating satisfactorily and the fuel has achieved another significant landmark of reaching a peak burn-up of 154,000 Wd/t, without any fuel failure. Based on our earlier Post-Irradiation Examination (PIE) of the fuel irradiated to 100,000 MWd/t, the target burn-up for the fuel was enhanced to 154,000 MWd/t. Prototype Fast Breeder

Reactor (PFBR) test fuel sub-assembly has reached a burn-up of 59,200 MWd/t, against the target burn-up of 100,000 MWd/t, at the design Linear Heat Rating (LHR) of 450 W/cm. Safety clearance is being obtained for increasing the target burn-up of FBTR fuel to 155,000 MWd/t. It is planned to convert FBTR core from carbide to MOX fuel gradually. Various important components are being analysed for the extension of the design life upto 30 years, as a first step. It is heartening to note that FBTR has attained capabilities to work at high availability factor of more than 80% in successive campaigns during the year 2005.

The Centre has created a new international bench-mark by successfully reprocessing the mixed carbide FBTR fuel, which has undergone a burn-up of 100,000 MWd/t, in the Lead Mini Cell (LMC). In order to understand the process and also to evaluate the critical equipment like chopper, dissolver and centrifugal extractor, fuel irradiated to very low burn-up, 25,000 MWd/t and 50,000 MWd/t were reprocessed, before taking up the fuel irradiated to 100,000 MWd/t. Various equipment developed have been subjected to rigorous tests and the experience gained is being utilised for the design of fast reactor reprocessing plant and also for the demonstration of reprocessing of the oxide fuel.

The technology development for the manufacture of all the major critical components, including the grid plate, required for PFBR has been completed successfully. Control and Safety Rod Drive Mechanism (CSRDM), the most important engineered safety components of the reactor, manufactured as a part of technology development and design validation, were qualified for PFBR, after rigorous testing in air and in hot sodium, representative of reactor conditions. We have gained expertise in steam generator facilities, sodium handling, design & development of sensors, development of structural materials and materials characterisation.

The detailed design of major components, systems and structures of the 500 MWe PFBR has been completed, with the objective of safety, techno-economic demonstration and indigenous manufacturability. Preliminary Safety Analysis Report (PSAR), which forms the most important document for reactor construction clearance from regulatory body, has been updated, reflecting the additional design inputs required by the safety committees. The plant layout has been finalised with emphasis on safety, constructability and compactness. Technical specifications for the procurement of important components of the reactor, including the turbo-generator and associated steam-water systems, diesel generators, switch yard, air conditioning & ventilation system and safety grade decay heat exchangers, have been released.

It is a matter of pride that we are taking active part in strengthening the activities related to Homi Bhabha National Institute (Deemed University), in terms of formulating the curriculum and academic structure. Focused collaborations have also been made with renowned academic and research institutions like IITs, IISc, SERC, Anna University, FCRI, Sathyabama University, Vellore Institute of Technology etc., for strengthening various R&D activities.

Boron Enrichment Plant (BEP) has achieved an enrichment above 65% in ^{10}B, which is the requirement for PFBR. A few Kg of boric acid was produced for conversion of the same into elemental boron. Based on the technology demonstrated, a plant is being set up at Manuguru to produce enriched boron for PFBR.

The Centre has been pursuing basic research in various frontier areas of science and technology and some of them such as radiation damage in reactor materials (D9 and modified D9 steels), applications-oriented superconductivity devices, MEMS ultrasonic transducers for NDT applications etc., find direct applications for PFBR. We are taking part in setting up of national facilities such as experimental programme on the INDUS-2 beam line at Raja Ramanna Centre for Advanced Technology (RRCAT), Indore and materials irradiation beam line at the upcoming medical cyclotron facility at Kolkata.

In a nutshell, notable achievements were made in design and engineering developments, fuel reprocessing, materials, safety, physics, chemistry, instrumentation & control and we have also witnessed marked improvement in engineering services and administration etc.

It is also worth mentioning that as a sequel to our earlier peer review in physical sciences, this year we have carried out peer review of chemical sciences with an eminent panel of experts. The panel has gone through detailed technical documents, listened to in-depth presentations and visited important laboratories. The panel has suggested valuable recommendations for making our Science R&D more vibrant and relevant for achieving higher impact. We are also taking steps to carry out similar peer review of our engineering sciences by an expert panel of high repute.

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It is a matter of pride that we are taking active part in strengthening the activities related to Homi Bhabha National Institute (Deemed University), in terms of formulating the curriculum and academic structure. Focused collaborations have also been made with renowned academic and research institutions like IITs, IISc, SERC, Anna University, FCRI, Sathyabama University, Vellore Institute of Technology etc., for strengthening various R&D activities.

With respect to General Services Organization (GSO), we should put in more sustained efforts in providing high quality of life to the residents, in terms of better service, care and comfort. We are taking necessary steps to ensure clean water in the townships and we should be able to implement this by 2006. It is also planned to provide a safety structural wall for the plant site and township as well as a reliable early warning system to the residents of the township. With respect to our Schools, I am happy that due to dedicated Principals, motivated teachers and supportive parents, we continue to excel in our students' performance and we should improve our past records at various board examinations and national competitions.

The goals ahead are clear – timely and necessary inputs to PFBR 500 MWe project, robust reprocessing technology, enhancing R&D for realising reliable, safe and economical FBRs and nuclear fuel cycle. We will endeavour to remain at the forefront of basic sciences, in select areas. We are also chartering a path of achieving significant breakthroughs by harnessing basic sciences for meeting technological challenges. FBR technology is destined to gain more importance and significance. We have to not only continue to march forward at faster pace but also to rededicate completely to put in all our efforts in this technology to make it robust. Our merits will be judged not only by the efforts we put in but by the results we produce. I am confident that our Centre can achieve better results and can become a bench mark organisation not only in the country but also internationally.

I truly believe that our emphasis on human resources and talents, their mentoring and motivating them to achieve greater heights and creating an environment of individual creativity and providing necessary challenges with right synergy are all well-thought out steps in our march for progress.

I would like to quote Shri Aditya K. Birla, an eminent industrialist known for his vision, dreams and for delivering the results in a competitive environment. *"Create an environment of Meritocracy: Spot and track nascent talent and create leaders with a rich mix of skills - who have exposure to different functions in the organization. Time and again, the supremacy of the human skill and spirit can not be over-emphasized. The success or failure of an organization depends on human beings, their talents, their initiatives, their ability to lead and co-ordinate with others and importantly, to work as a competitive team. It also depends on the ability of the organization to motivate them to greater heights and to provide necessary challenges…"*. I truly believe that our emphasis on human resources and talents, their mentoring and motivating them to achieve greater heights and creating an environment of individual creativity and providing necessary challenges with right synergy are all well-thought out steps in our march for progress. I believe our vision is truly tall and our human resources have to continuously grow and match with this. I have all the faith in all of you and full confidence that collectively, we are on a path of rapid progress of realizing our dreams and vision of achieving breakthroughs in our pursuit of basic research as well as global leadership in Fast Reactors and associated Fuel Cycle technologies.

Wish you and your families all the best in the year 2006.

With my best wishes and warm regards,

Baldev Raj
Director

Milestone: Twenty years of successful operation of FBTR

The Fast Breeder Test reactor turned twenty on 18th October, 2005. Starting with a core of 23 fuel subassemblies rated for 10.5 MWt, the reactor core has been progressively enlarged by adding Mark-I and Mark-II subassemblies. The reactor has completed 13 irradiation campaigns, with the core for the last campaign rated for 16 MWt and having 29 MK-I and 13 MK-II fuel subassemblies, in addition to a PFBR test fuel subassembly. Various milestones crossed by FBTR are given in Table-I. The progressive evolution of reactor power and operating peak LHR are given in Fig. 1.

The performance statistics of reactor operation as of 18th October are summarized in Table-II.

The major challenges faced include reactor vessel deflection due to cover gas convection in the annular spaces at the top, fuel handling incident which warranted in-situ cutting of the guide tube by a special tool developed by BARC (Fig.2), main boiler feed pump seizure, core cover plate getting stuck, reactivity transients, leaks from the biological shield cooling circuit coils and sodium leak from the primary sodium purification circuit. These affected the reactor availability upto the 9th irradiation campaign. The reactor availability from the 10th campaign onwards has been more than 75%.

As an irradiation facility, Zr-Nb alloys developed indigenously for the PHWR have been irradiated in FBTR and qualified. Fuel of composition simulating the PFBR fuel is at present undergoing irradiation.

The performance of the nuclear systems has been very good. The sodium pumps have been in continuous service most of the time, except during fuel handling, preventive maintenance etc. Availability of the pumps on demand has been excellent- more than 95%. Though occasional problems of high vibration and arcing in the DC generators have been faced in the Ward Leonard drives, the pumps themselves have been trouble free except occasional increase in oil leaks, warranting replacement of the mechanical seals. Sodium purity is well maintained, with the plugging temperature always below 105°C. Cover gas purity and system integrity are so well maintained that even with the cold traps out of service for three months, the plugging temperatures are below 105°C. So far, 52 fuel handling campaigns have been completed, and all the 46 campaigns after the fuel handling incident of 1987 have been smooth. Integrity tests of the Reactor Containment Building have been carried out 11 times so far, and the leak rate has always been below the permissible leak rate. Visual inspection of the reactor vessel internals has been carried out at two year intervals and have been found to be healthy, without much of sodium deposits (Fig.3). Periodic visual inspection of the primary and secondary piping hanger settings, ultrasonic inspection of the secondary sodium piping and steam generator shell welds and liquid penetrant examination of secondary sodium pump supports have confirmed the overall integrity of the sodium systems. The cumulative radiation dose to personnel during the two decades of operation is only 67 person-mSv and the cumulative stack release is 440 Ci of Ar^{41}.

Table-I

MILESTONES

18th Oct 1985	First criticality
Nov 89	Sodium valved in into Steam Generator (SG)
Jan 93	Water valved into SG
Dec 93	Power raised to 10.5 MWt
94-95	Safety Related Engineering Experiments
May 96	MK-I burn-up of 25 GWd/t
July 97	TG synchronised to grid
98-99	Zr-Nb irradiation for PHWR
Apr 99	MK-I burn-up of 50 GWd/t
Mar 2002	Power raised to 17.4 MWt
Sep 2002	MK-I burn-up of 100 GWd/t
July 2003	Start of PFBR Test Fuel Irradiation
Oct 2005	MK-I burn-up of 150 GWd/t

FBTR Milestones

Table II

SUMMARY OF PERFORMANCE STATISTICS
(as on 18th October 2005)

Parameter	Unit	Since first criticality
Maximum Power	(MWt)	17.4
Maximum LHR	(W/cm)	400
Maximum bulk sodium temperature	(^{O}C)	444
Operating time		
High Power	h	20,428
Low Power	h	16,490
Total	h	36,918
Thermal energy produced	(MWh)	262748
TG synchronisation time	(h)	5228
Electrical energy generated	MU	5.425
EFPD at LHR of 320 W/cm	(d)	810
Peak burn-up	(GWd/t)	148.4
Longest operating campaign	(d)	54
Cumulative time of 4X Na pumps operation	(h)	5,45,556
SG operation	(h)	20,428
No. of LOR / scrams		245 / 158

Fig.1: FBTR Power Evolution

Unique features and achievements of FBTR

- Liquid metal Sodium as the coolant.
- Excellent maintenance of the purity of tons of liquid Sodium for two decades
- Record performance of the Sodium pumps for the circulation of Sodium
- High Pu monocarbide fuel, used for the first time in the world.
- The burn-up logged by this fuel is an international record.
- The operating temperatures of FBTR heat transport systems are higher than in any other nuclear reactor in India.
- The steam pressure is the highest.
- The turbine is unique in that it is a low power turbine using high temperature, high pressure steam.
- Perhaps the purest DM water among all plants is made in FBTR, arising out of the demand from the once-through steam generators.

More than 500 modifications have been carried out in the plant to enhance plant safety, availability and operator convenience. Major replacements include the two sub-systems of Central Data Processing System, neutronic channels, single phase 220 V UPS, station batteries, fire alarm system, nitrogen plant, DM plant and one main boiler feed pump. To avoid the several spurious trips that were originating from the steam-water system, the contact type of feed water heaters were replaced by shell & tube type. To improve

Fig.2 In-situ Cutting of Guide Tube on the Reactor used in 1988

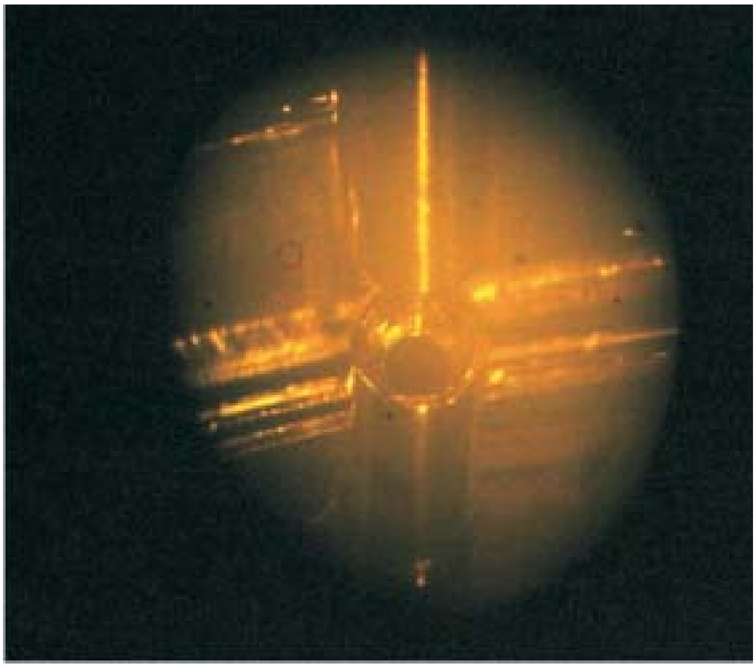

Fig.3 Siphon Break Pipe and the reflection of its open end in sodium

the reliability of the Steam Generator Leak Detection system, triplication of the system in both the loops was taken up, and has been completed for the east loop. For the west loop, the system has been duplicated and triplication will be completed shortly. Augmentation of the ventilation system of turbine building and steam generator building and augmentation of the chilled water supply to the plant are in progress.

Since FBTR has completed 20 calendar years of operation, shortly there will be a Periodic Safety Review by AERB for relicensing the plant. Towards this, residual life assessment of the nuclear system components based on the operational data and physical assessment of the health of the various systems, sub-systems, structures and components by plant walk-down is being undertaken. Due to operation with the small carbide core, the effective life consumed by the nuclear systems so far is only about 3 years. The reactor is hence still left with enough residual life to complete its mission as a test-bed for fast reactor fuels and materials. In the next few years, it is planned to (a) irradiate metallic fuel and vibro-compacted oxide fuel, (b) demonstrate the potential of FBTR as a breeder by breeding U^{233} in Thoria blankets surrounding the core and (c) to demonstrate the closing of fuel cycle using several metallic fuel subassemblies.

It may be noted that FBTR is unique in several respects vis-à-vis other nuclear plants in India. Its unique achievements have given us the confidence to feel that we have mastered fast reactor technology. The operational experience gained through twenty years of operation of FBTR has provided us enough strength to confidently embark on the construction of 500 MWe prototype fast breeder reactor (PFBR) at Kalpakkam.

(Reported by Reactor Operation & Maintenance Group)

Design and Testing of Eddy Current Position Sensor for DSRDM

In PFBR, there are three Diverse Safety Rod Drive Mechanisms (DSRDM) in the control plug, which hold the diverse safety rods (DSR). During normal operation, DSR are held outside the active core region by an electromagnet. On receiving SCRAM signal, the electromagnet de-energizes and drops the DSR, which falls under gravity in sodium. DSR gets decelerated due to damping action of sodium in the dash-pot after traveling a certain free-fall distance. For measurement of free fall time and detection of DSR at its bottom most position, an Eddy Current Position Sensor (ECPS) based on eddy current technique was designed, fabricated and tested in air and sodium.

The basic design was arrived at after analyzing different design options. Also closed circuit analysis was carried out to estimate the sensitivity. A sensor having circuit configuration as shown in Fig.1 was chosen for design. The primary coil, placed

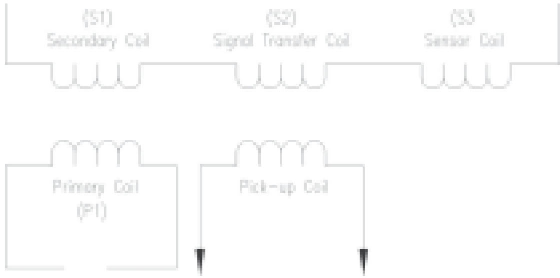

Fig. 1 : ECPS Circuit Configuration

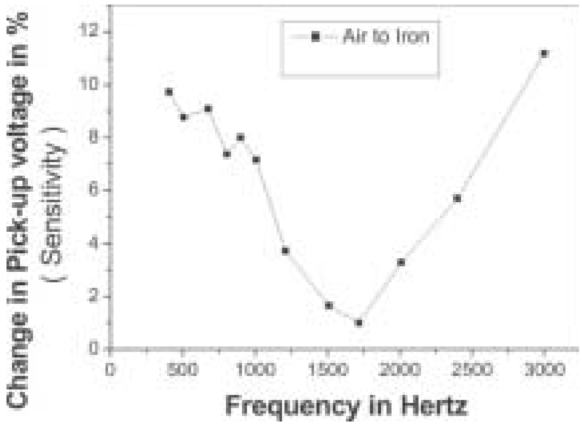

Fig. 3 : Test results in Air

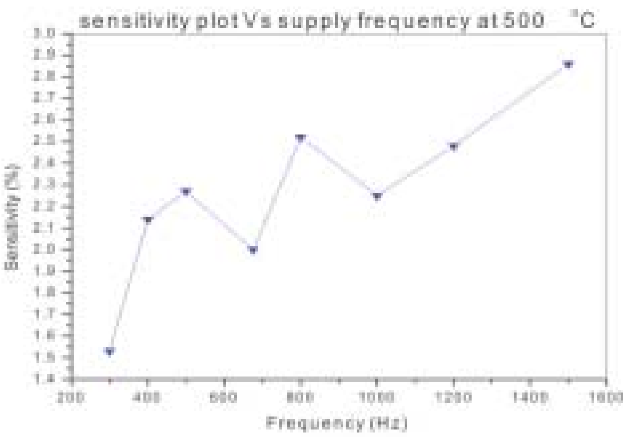

Fig. 4 : Sodium testing result

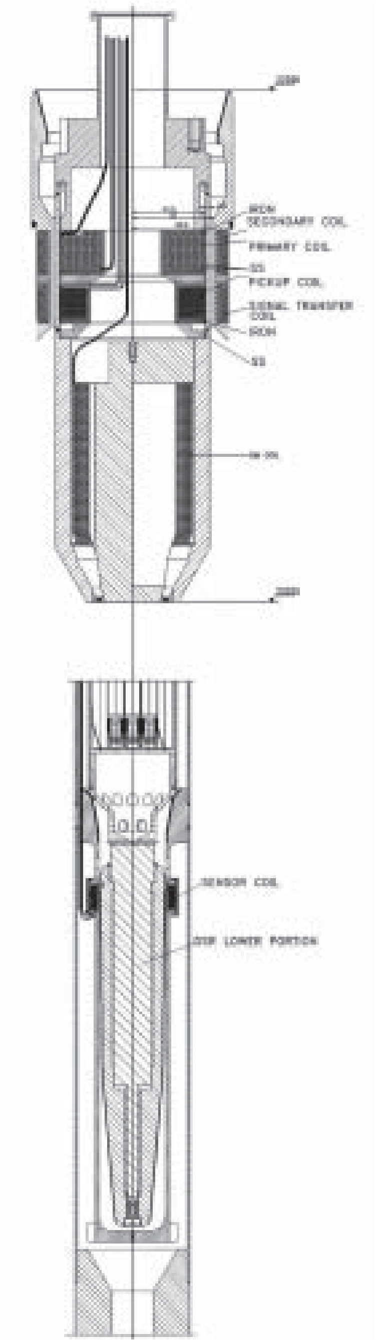

Fig. 2: ECPS in DSRDM and DSR

Fig. 5 : Photo of ECPS Model

on the mobile assembly of DSRDM is excited with current. A pick-up coil is also placed below the primary coil in same axis for getting the output signal. Secondary, signal transfer & sensor coils are placed as shown in Fig.2. Space constraint is a challenge for accommodating ECPS in DSRDM. The induced voltage in secondary would drive a circulating current in all the three coils on secondary side. The magnitude and phase of this current depends on the total impedance of coils on secondary side. The impedance of sensor coil changes when the DSR is in the deposited condition as compared to non-deposited condition. Accordingly, flux linkage with pick-up coil varies, thereby changing the voltage induced in it. This indicates presence of DSR near sensor coil. A parametric study was done with respect to frequency, bobbin dimension and number of turns.

The ECPS model was fabricated for testing. All coils were made with MI cables for suitability to high temperature and sodium service. The SS spacer between primary and pickup coil was replaced with copper spacer to reduce the cross coupling and to concentrate the flux in the intended path. It was first tested in air to see the functioning. Air testing result is shown in Fig. 3. The sensitivity is of the order of 10%at around 500 Hz

The ECPS model was introduced in SILVERINA loop for sodium testing. The tests were conducted at various temperatures in sodium. The result at 500 ^{o}C in sodium is shown in Fig.4. As frequency increases absolute value of pickup voltage comes down. From this point of view, operating frequency should be less than 1000 Hz and in this range average sensitivity is around 2 % at 500 Hz. The reduction in sensitivity during sodium testing as compared to air is attributed to the following points:

1. Presence of sodium in between the primary and secondary coils
2. Presence of sodium inside the sheath side coils and
3. Increase in resistance of the sheath side coils with respect to temperature.

Further design improvement will be carried out based on these experiences. The conducted test on ECPS model has proved the feasibility of such a sensor for DSRDM of PFBR. A photo of the test setup is shown in Fig. 5.

(Reported by Task Force on Eddy Current Position Sensor for Diverse Safety Rod)

Parallel computing facility for real-time atmospheric dispersion forecast

Atmospheric dispersion forecast modelling in a regional scale is known to be a huge task as it handles enormous amount of data for initial and boundary conditions and, when it comes to implementing an operational system in ‘live’ mode, it should deliver the forecast products sufficiently in advance. Hence research was done on implementing a parallelized real-time atmospheric dispersion forecast system using cluster computing techniques. Initially, an extensive survey of different types of networking techniques available and interaction with experts at Institute of Mathematical Sciences (IMSc), Chennai were carried out. A hands-on experience on various platforms (8node SMS cluster, IGCAR, SCALI and KABRU clusters at IMSc) in configuring the system for the specific task resulted in the choice of a simple Gigabit Ethernet based cluster configuration that provides adequate efficiency for the present application. A cost-effective high performance scalable Linux cluster computing system was successfully commissioned at RSD and the dispersion forecast system is being operated in live mode. Features of the cluster /has been published in / can be found in IGC Newsletter Vol.66, Oct.’05.

Brief description of the real-time atmospheric dispersion forecast system

The numerical modelling system for real-time application consists of a parallelised state-of-science regional scale weather forecast model MM5 and a dispersion-cum-dose assessment model.

MM5 is designed for high-resolution forecasts of atmospheric state. It includes a finite difference formulation of the time-dependent Navier Stokes equations plus physics computations for the simulation of clouds, radiation, moist convection, surface boundary heat-fluxes etc. in a cubical three-dimensional region representing the atmosphere.

MM5 works on distributed memory (DM) parallelism using message-passing across the DM provided by parallel runtime system library RSL which is a FORTRAN callable parallel library for finite difference weather models. The RSL is a portable library which provides two supporting mechanisms for parallelization of finite difference numerical scheme. One is the communication interface (buffer allocation, copying, routing, and asynchronous communication) and the other is index transformation (removes iteration over global horizontal indices from the original program and inserts the local horizontal indices at runtime). The changes in the code for parallelism is automated using FLIC, a Fortran loop and index converter. This is a parser-based source translation tool that automates the conversion of program loops and array indices for distributed-memory parallel computers.

The conversion of array indices in MM5 is as follows. The model physical domain is represented by a 100(I_x) X 100(J_y) horizontal grid mesh with 23 logarithmically distributed vertical levels. Three domains with resolution of 18km, 6km and 2km each respectively are simulated in a nested mode. The 36 logical processors available would divide the domain in to 6 X 6 sub domains of 17(I_x) X 17(J_y) each and compute the dependent variables for a single time step (Fig.1). At the end of the computation, values would be integrated across the sub domain through RSL. Thus the prognosis of the model would continue for the entire period of the forecast.

As a first stage of the project the parallel computing cluster executes MM5 and provides on-line input meteorological parameters to a dispersion model. The core part of the project is to run MM5. Initial input data is taken from the objectively analysed and interpolated observed data from national and global weather services in a regular interval of time. The spatial resolution is 250km for the global data. The boundary condition is also periodically updated (every 6h) from the global forecast model. Therefore the problem involves downloading of huge data (~0.5GB) from national (National Centre for Medium Range Weather Forecast - NCMRWF) or open source (National Centre for Environmental Protection-NCEP, US) twice to four times a day depending upon requirement of forecast accuracy. This is followed by pre-processing in MM5 and running of parallel simulation. The hourly output of the forecast is fed to a serial run of a dispersion model FLEXPART. Finally, a graphical interpolation program is executed to generate visual displays that would be dynamically published in a web page or exported to a decision support system. The entire procedure, as shown in FIG.2, is scripted in the Linux shell and resides in the event scheduler daemon CRON. The cycle of downloading and pre-processing starts at the beginning of the day (00 IST)and the parallel model is run in all the nodes of the cluster.

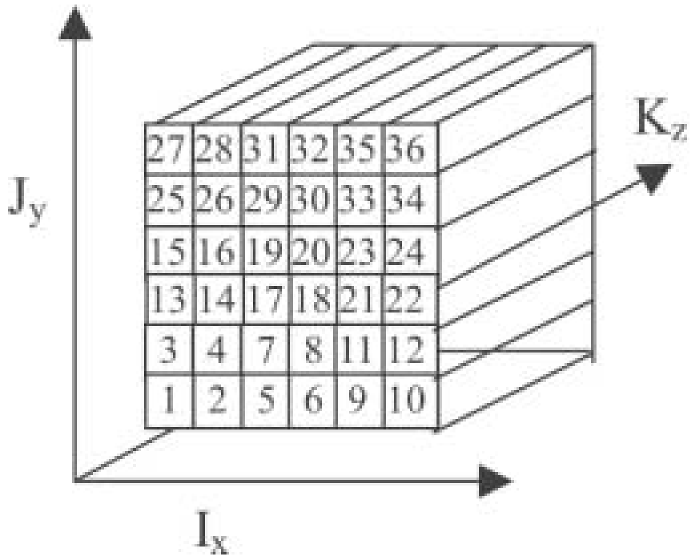

Fig.1: Memory usage reduction on multi-processors

[Division of model horizontal domain (100 X100) into 36 sub domains corresponding to 36 processors]

Components of meteorological forecast model

- Terrain data (topography, landcover, soil texture and deep soil temperature – generated using GIS) as realistic lower boundary
- Two way nested multi-domains for coarse, medium and fine resolution forecast for dynamic aliasing of different scales of atmospheric motion.
- Various Turbulence closure schemes for sub-grid scale processes (convective precipitation, radiation and boundary layer processes R&D still continues)

Performance evaluation of the Cluster

The cluster processing speed is found to be about 65Mflops when 8+1 nodes (36 logical processors) are engaged. A better and widely used index with which runtime performance is judged is described by Amdahl's Law. It is a law governing the 'speedup' of using parallel processors on a problem, versus using only one serial processor. Speedup is defined as the time it takes a program to execute in serial (with one processor) divided by the time it takes to execute in parallel (with many processors). The formula for speedup S is: $S = T(1)/T(N)$

Where T(j) is the time it takes to execute the program when using N processors. A factor on which the speedup depends upon is the fraction of the problem that can be parallelised. Suppose α is the fraction of the problem that cannot be parallelised. If the serial part of the program is performed in $\alpha \times T(1)$ time, then, ideally, the parallel

part is performed in

time. Thus the speedup is given by

$$S = \frac{((1-\alpha)\times T(1))}{((1-\alpha)+(\alpha N))}$$

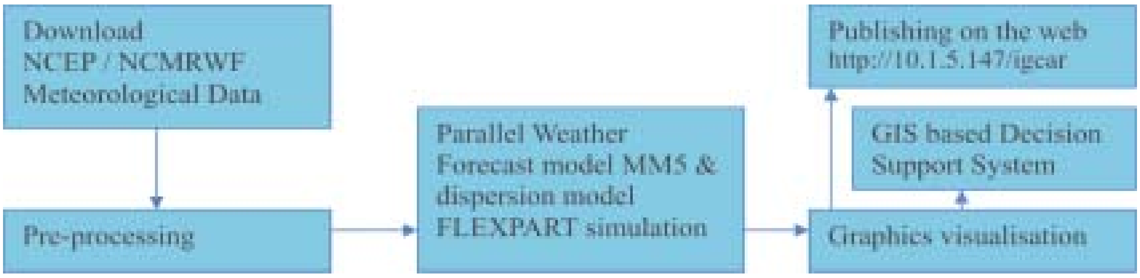

Fig. 2: Major components of the simulation system

Distributed Memory Parallelism

- Increase computational and memory resources available for larger and faster runs by engaging more number of computers
- A Shared-Memory parallelism possible using Cray Microtasking directives and recently, OpenMP directives
- In Distributed Memory Parallelism, processors stores only a part of the model domain in the local memory and works on the problem by passing messages across the network
- DM system is scalable because it eliminates bottlenecks of sharing the same bus or memory
- Cost effective as it can be built with off-the-shelf components

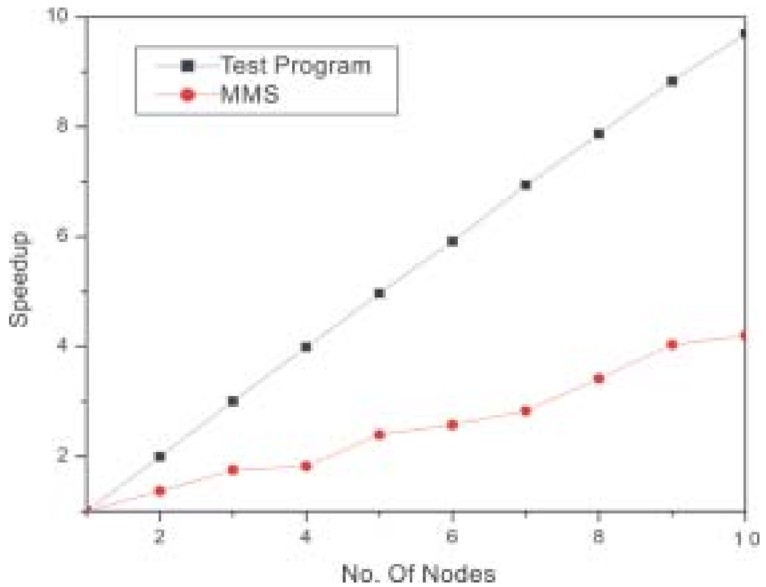

Fig.3. Speedup diagram for RSD

If the problem can be converted into a 100% parallel code, the speedup would be theoretically equal to as many number of processors as can be employed. For example, for a 10 node cluster, the speedup would be theoretically 10. If 10% of the problem can not be converted and to be computed in series mode, then the speedup would be only about 5 in 10 nodes; for 20% serial problem, the speedup would be 3.5 and so on. ***Therefore the effective and economic use of a cluster primarily relies upon the computational nature of the problem.*** The dispersion forecast system consists of a CFD weather forecast model MM5 and a Monte Carlo model FLEXPART and thus can be converted into a parallel code to a very large extent.

In order to estimate the cluster performance parameters, a test program, based on Monte Carlo algorithm and matrix multiplication is used from OCTAVE Parallel programming library. In the present cluster, these parameters are estimated and the speedup S is 8.82 in 9 nodes.

Efficiency is the speedup, divided by the number of processors used. Efficiency (%) = S / no. of nodes = 8.823/ 9 =98 %.

However, in MM5 due to inclusion of several boundary layer and cloud physics algorithms, the speedup currently observed is 4.2 and the efficiency is 46% .This result is similar to what has been achieved by others elsewhere. A comparative speedup diagram is shown in Fig.3.The runtime reduction as a function

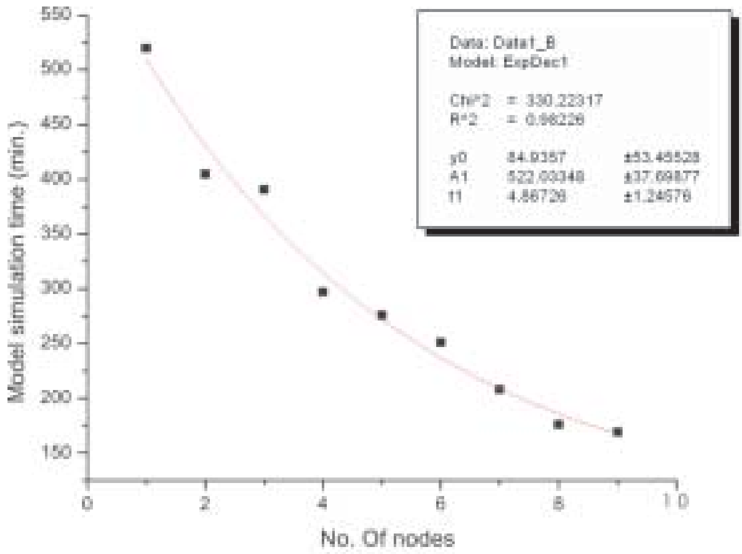

Fig. 4 : Runtime *Vs.* Nodes

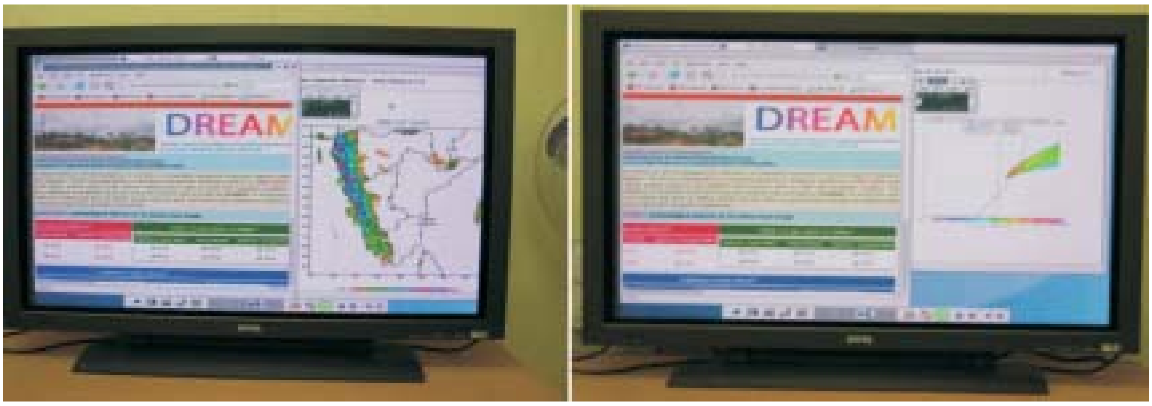

Fig. 5 : Results displayed on the web page in the local LAN

of no. of nodes is shown in Fig.4. A Gaussian fit to the data is given by:

$T_n = T_{sat.} + T_1 . \mathrm{Exp}(-n/\lambda)$. where $T_{sat.}$ is 85 minutes and λ is 4.87.

The curve shows that the scalability would saturate at 16 nodes for the current problem of MM5 execution and little improvement is possible in the Gigabit Ethernet switch mode cluster. Experience elsewhere also confirms that the ***switch mode clustering technique has a saturation of the scalability at about 32 nodes independent of the computational problem.***

The success was no doubt only after suffering a long-time torture of floating point errors due to segmentation faults in memory distribution and numerous hitches in networking and OS configuration.

Daily weather and dispersion forecast is available on a trial basis in the intranet web page at http://10.1.5.147/igcar. A typical web page showing the weather and dispersion forecast is presented in Fig.5. It is to be noted that the modelling system is still in a research and testing stage and extensive validation through meteorological and dispersion field experiments needs to be carried in order to claim operational utility. However modelling systems are employed elsewhere even in this stage for deriving inputs for decision making during emergencies.

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

Studies on Flow Blockage in PFBR Test Subassembly

E.H.V.M. RAO
DOB: 13.07.80

obtained his B.Tech degree in Mechanical Engineering from Jawaharlal Nehru Technological University, Hyderabad in 2002.

He is from 46th batch of BARC training school and joined IGCAR as Scientific Officer (SO/C) in September 2003.

Fuel subassembly blockage is one of the important safety issues in the operation of the fast reactor as it may lead to local heating in subassemblies with a potential to cause fuel melt down. Steel chips/ particles resulting from the machining process in the construction stage or accumulation of non-fuel debris arising from corrosion/ erosion or other reaction products of primary sodium with organic materials may be transported and settle in the fuel subassembly causing flow blockage. If the blockage reaches a critical size, it may result in over heating of pins causing local sodium boiling, dry-out and melting of clad and fuel pin. Hence understanding of the blockage phenomenon is very important.

To investigate the implications of blockage due to external debris and provide data for porous blockage due to debris particles, an experimental test loop with 37-pin fast reactor test subassembly was set up at Safety Engineering Division. The schematic diagram of experimental loop and cross-section of subassembly are given in the Fig.1 and Fig.2. The diameters of dummy fuel pin and spacer wire are 6.6 mm, 1.65 mm respectively. The fuel pin pitch is 8.28 mm and helical pitch of the spacer wire is 200 mm. A venturi meter with a range of 17- 30 m^3/hr was used for flow measurement. Differential Pressure (DP) measurement system with a range of 0 to 1500 kPa was used for the pressure drop measurement along the test section.

Four sizes of debris (closer to the spacer wire diameter viz., 2.0 mm, 1.6 mm, 1.2 mm and 0.8 mm) were chosen as they fall in the range of particles that can form blockage in the subassembly. Experiments were carriedout at 5 ppm debris concentration. In all the runs, sodium flow rate through the test subassembly was maintained at 30 m^3/hr to achieve a velocity of 8 m/s, which is equal to the velocity in the maximum rated PFBR subassembly.

Debris is introduced into the loop main tank in equal mass lots at every half an hour duration. The DP measurement was used as characterization of blockage formation in the subassembly with addition of debris. Using ADAM data acquisition system, real time data of flow rate, pressure drop and temperature readings were recorded. The test subassembly was marked into 30 sections of 30 mm each. After each run, the hexagonal split housing of the test section is opened for videography and for the actual count of number of particles collected at each of the 30 sections of the test subassembly length. From this, the distribution pattern of debris along the pin length and volume fraction occupied by it in each section are obtained.

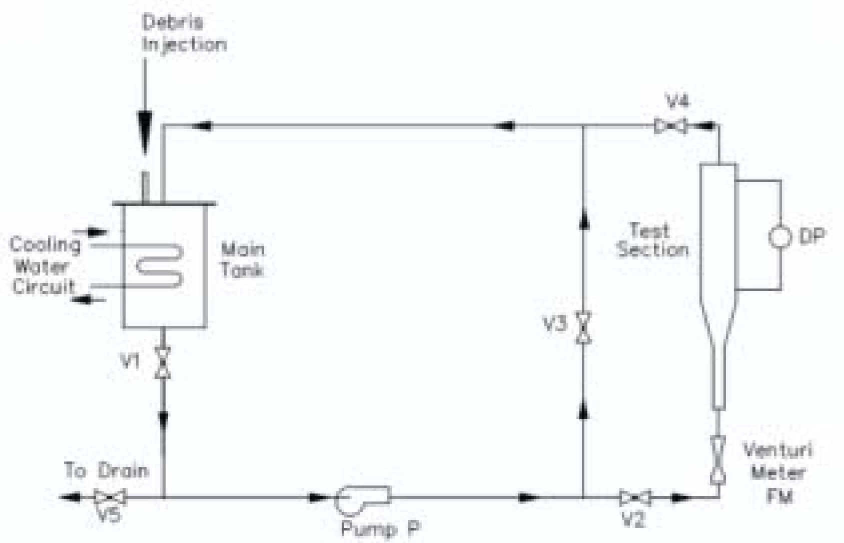

Fig.1 Schematic layout of experimental loop

The variation of pressure drop for different size particles with debris added in 0.5 ppm steps every 30 minutes until a total concentration of 5 ppm is shown in Fig.3. In the runs with 1.6 mm size and 2 mm size debris, immediate increase in the pressure drop was observed in contrast to the other two sizes 1.2 mm and 0.8 mm, where gradual rise occurred in few minutes (~ 5 to 10 min) after the debris addition signifying immediate settlement of the bigger debris in the test subassembly than the smaller size debris. The difference in DP variation for different size particles used is shown in Fig.4.

Particle distribution pattern: The typical debris settlement at a section in the subassembly is shown in Fig.5.

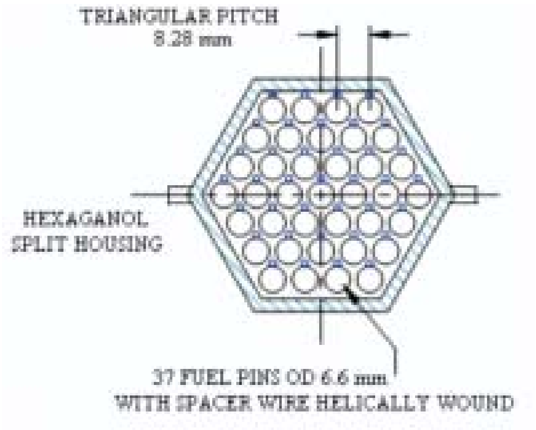

Fig.2: Crosssection of 37 pin subassembly

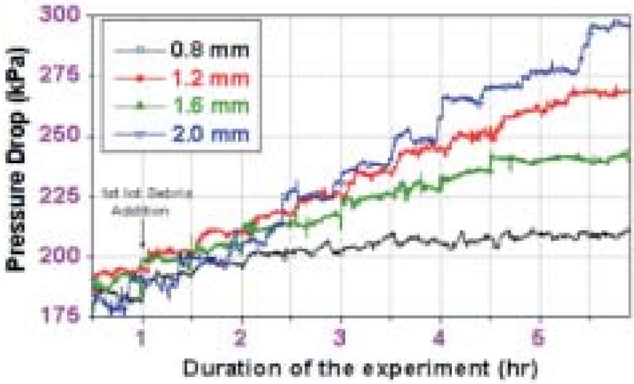

Fig. 3 : DP Variation in 5 ppm concentration runs

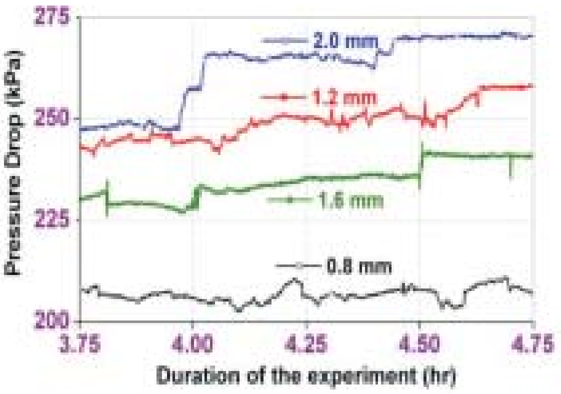

Fig. 4 : Difference in DP Variation

Fig.5: Debris settlement at a section in subassembly

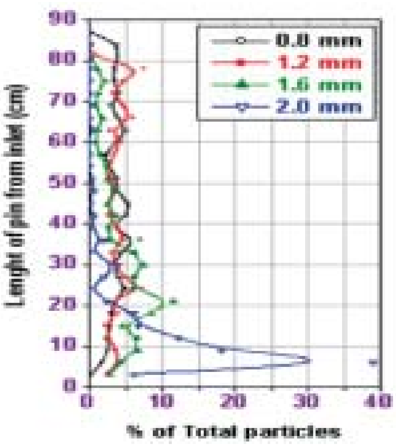

Fig. 6 : Settlement of different size Debris at 5 ppm concentration

Table 1

Pressure drop Coefficients at 5 ppm concnetration

Debris Size (mm)	Pressure Drop* ΔP (kPa)	Pressure Drop** Coeffficent ( )
0.8	206	7.495
1.2	265	9.645
1.6	240	8.734
2.0	298	10.847

*Pressure Drop with out debris is 180 kPa

**Pressure Drop Coefficient

Experiments with 1.6 mm debris showed a tendency to get collected more in the bottom half than the top half of the subassembly whereas the 2 mm size debris showed settlement at the bottom of the subassembly viz., near the inlet of the bundle. 1.2 mm size debris had a uniform distribution through out the length of the subassembly. 0.8 mm size debris showed that, only 25% of the particles were settled in the fuel section and the particle distribution is uniform throughout the subassembly. The settlement of different sizes of debris is given in fig.5.

The pressure drop coefficient which is function of particle diameter and concentration is given in table.1 for different debris sizes at 5 ppm concentration.

The experiments helped in studying the settlement of different size particles along the subassembly and the role of particle size in blockage creation. The pressure drop data obtained is useful in finding out the flow resistance caused by the particles in the subassembly, from which the flow reduction due to blockage can be assessed. Further experiments are planned with small size debris particles. Mathematical modeling also has been taken up to obtain a comprehensive understanding of this important phenomenon.

(E. H. V. M. Rao and Colleagues, Safety Engineering Division, Safety Group)

High Pressure Structural Phase Stability Studies on Thorium Digallide

N.R. Sanjay Kumar

DOB: 30.01.76

obtained MSc (Physics) degree from Bangalore University in 2000 and joined IGCAR directly as Scientific Officer (SO/C) in October 2001.

Study of structural stability and phase transition behaviour of materials under high pressure is an important aspect of materials research. Application of pressure leads to lattice compression and changes in the electronic structure. This leads to drastic changes in their physical and chemical properties. For instance, closing of energy gaps lead to metal-insulator transitions, shift in energy bands lead to interband electron and valence transitions, change in topology of the Fermi surface lead to electronic transitions and so forth. Also, the equation of state of materials is a vital information for materials scientists and engineers. Towards applied research, pressure tuning offers a novel method for studying possible improved properties in compressed materials, for instance ductility, thermoelectric power etc.,. Observation of improved properties under pressure can provide targets for synthesis at ambient pressure, ie., design of novel materials.

In our laboratory, we have a well defined program of studying the pressure induced behaviour of the rare-earths and actinide based binary intermetallics. In this article, the high pressure behaviour of $ThGa_2$ is reported.

$ThGa_2$ stabilizes in tetragonal structure at NTP. It was prepared and characterized in our laboratory and its lattice parameters were found to be a = 4.246±0.001 Å and c = 14.752±0.005Å. The high precision x-ray data obtained by us on this system has been accepted by the *International Center for Diffraction Data* (ICDD, USA) as a standard Powder Diffraction File.

Our earlier High-pressure X-ray diffraction (HPXRD) experiments on $ThAl_2$ showed interesting structural transitions from hexagonal to orthorhombic to tetragonal structures with increasing pressure. $ThGa_2$ being homologus to $ThAl_2$, is also expected to show some interesting structural transitions.

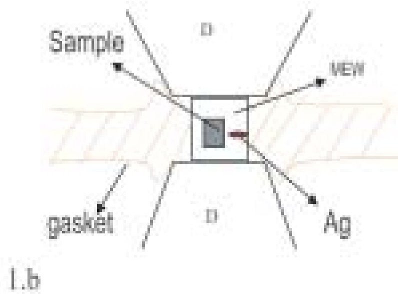

Fig1: (a) DAC mounted in pressure cell holder. (b) Schematic of sample assembly for HPXRD. D stands for diamonds mounted on cylinder and piston, sample and Silver loaded in the gasket hole of Φ ~ 200 µm, MEW stands for Methanol Ethanol and Water mixture.

Fig. 2: Guiner Diffractometer setup. (a) 18 KW rotating anode X-ray generator, Mo target. (b) Crystal monochromator (c) Pressure cell holder (d) Diamond anvil cell (e) Position sensitive detector

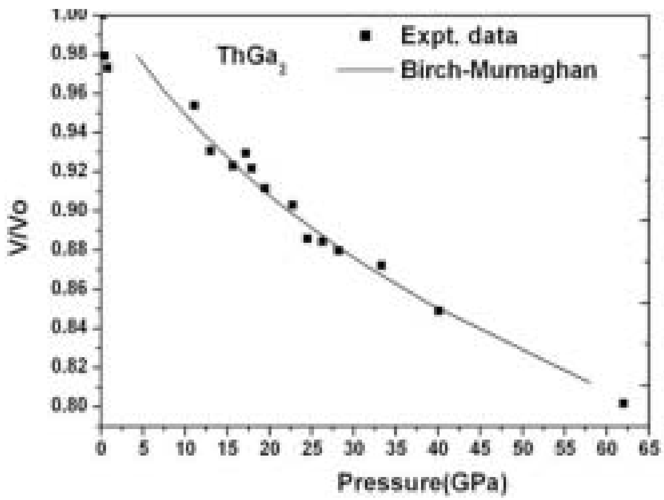

Fig. 3: V/V_0 vs pressure. Birch Murnaghan equation of state is used to carry out curve fitting.

HPXRD studies on $ThGa_2$ were carried out up to ~ 62 GPa with a Mao-Bell type diamond anvil cell (DAC) using a custom-built high precision Guinier diffractometer. DAC is miniature high pressure device capable of generating multi-megabar (1 Mbar=100 GPa) static pressures. DAC is essentially a piston and cylinder arrangement in which two gem quality diamonds are mounted on the cylinder and piston so as to have opposed anvil configuration. The contact area of the diamond anvils is ~ 500 µm. In between these two diamond anvils, a hard metal gasket of thickness ~ 30 – 40 µm and with a central hole of diameter ~ 100 – 200 µm is mounted. The sample in the form of powder or a small speck along with the pressure transmitting fluid and the pressure marker are placed in this tiny gasket hole. Pressure cell holder along with the DAC is shown in Fig.1.a, and a schematic of the sample assembly for HPXRD is shown in Fig. 1.b. The photograph of the high pressure Guinier diffractometer system is shown in Fig. 2. The overall resolution is found to be dd/d = 0.01-0.02.

A finely powdered sample mixed with the pressure calibrant Ag was loaded into the stainless-steel gasket hole along with a mixture of methanol, ethanol and water (MEW) in the ratio of 16:3:1 as the pressure-transmitting fluid. The equation of state of Ag was used for pressure calibration.

HPXRD experiments on $ThGa_2$ were carried up to 62 GPa. From the observed XRD spectrum, the pressure dependence of the d-spacings and hence the lattice parameters *a* and *c* were calculated. The cell volume was computed from these lattice parameters. The noramalised cell volume V/V_0 vs. pressure is shown in Fig. 3. It was noticed that unit cell volume dropped by almost 4% at pressures as low as 0.2 GPa. We believe this may be due to an isostructural transition. The structure remained stable up to the maximum pressure studied. The P-V data was fitted to the Birch-Murnaghan (BM) equation of state and the bulk modulus was found to be 169 GPa.

To understand the stability of the tetragonal structure of $ThGa_2$ over a large pressure range, we utilized the structural stability maps. These structural stability regimes for various types of systems are arrived at using electron counting rules. These rules are derived from both experiments as well a Hückel type theory. The observed/predicted zone of stability for tetragonal and orthorhombic structures is from 10 to 13 number of electrons per formula unit. $ThGa_2$ has 10 electrons per formula unit. Under pressure, the number of free electrons per formula unit is expected to increase and hence its structural stability regime may extend up to 13 electrons per formula unit. Our band structure calculations clearly show that as a function of pressure, the electron transfer among the various bands is very less. This may be the probable reason for the stability of this compound up to 62 GPa. The density of states histograms at different compressions were also computed, and it revealed that the Fermi level remains fixed to a pseudo-gap at compression up to 0.75 times the equilibrium volume.

This clearly indicates that $ThGa_2$ is very stable and it is not undergoing any structural phase transition, unlike its homologue $ThAl_2$. We have also observed from this study, that the density of states at Fermi level gradually decreases and also there is not much of electron transfer under pressure. In summary, the band structure calculation supports the experimental observation that $ThGa_2$ remains in the same structure up to about 60 GPa and predicts that the possible reason for this stability may be due to the non-transfer of electrons from s to d level under pressure.

(N.R. Sanjay Kumar and colleagues, Advanced Material Section, Material Science Division, Metallurgy and Materials Group)

Celebration of twenty years of operation of FBTR

Dr. Anil Kakodkar, Chairman, AEC and Secretary, DAE participating in the FBTR celebration function at SRI Guest House. Seen in the picture are Shri B. Rajendran, Associate Director, (O&M) , Dr. Baldev Raj, Director, IGCAR and Shri P. V. Ramalingam, Director, ROMG.

The Fast Breeder Test Reactor (FBTR) turned twenty years on 18th October 2005. As part of celebrations of 20 years of successful operation of FBTR, a seminar in Tamil was conducted on 18th October 2005 under the auspices of INS, Kalpakkam chapter, with participation from all FBTR staff. Twenty nine papers were presented in the seminar covering the entire field of operation and maintenance aspects of various components. All the presentations were in made in Power Point by the staff, and there was full participation by the staff throughout the seminar, which showed their enthusiasm. On 23rd October an Open House for FBTR was conducted when the family members of FBTR employees visited the plant. About 1500 persons visited FBTR, and most of them visited the Reactor Containment Building, with the reactor operating at 16 MWt. A video film on FBTR, specially made for this occasion to familiarize the family members about the role of FBTR in Indian energy scenario, was shown in the lecture hall for all the batches of visitors. On 2nd November 2005 a family get-together of FBTR employees was conducted in Anupuram SRI guest house. Dr. Anil Kakodkar, Chairman, AEC and Secretary, DAE and Dr. Baldev Raj, Director, IGCAR graced the function.

(Reported by Shri P. V. Ramalingam, ROMG)

A Fountain put up before the FBTR complex to commemorate twenty years of operation.

Awards & Honours

- Dr. Baldev Raj has been conferred with the prestigious 14th Nayudamma Memorial Award, instituted by Dr. Y. Nayudamma Memorial Trust, Tenali, Andhra Pradesh for the year 2005 for his significant contributions in the area of Fast Reactor Science and Technology.
- Dr. S. Venugopal has been elected as a Fellow of Indian National academy of Engineering (INAE).
- Indian Chemical Institute (ICI), India, IIChE-NOCIL Award for Excellence in Design or Development of Process Plant and equipment for the year 2005 has been awarded to Dr. Baldev Raj, Shri R.Natarajan, Dr. S.B.Koganti, Shri M.Venkataraman, Shri V.Sundararaman and Shri A. Ravisankar of Reprocessing Group (RpG) for their work on "*Fuel Reprocessing of Unique Plutonium based Carbide Fuel*".
- Indian Chemical Institute (ICI), India IIChE Award for Excellence in Process or Product Development for the year 2005 has been awarded to Dr. C.Anand Babu, Dr. B.K.Sharma and Shri. G.Mohanakrishnan of Fast Reactor Technology Group (FRTG) for their work on "*Ion exchange chromatographic separation of isotopes of boron*".

Dr P.R.Vasudeva Rao, Chairman, Editorial Committee
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