IGC newsletter

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# From the Director's Desk

INSIDE



## The evolution of Chemistry programme at Indira Gandhi Centre for Atomic Research

Chemistry has played an important role in the development of nuclear energy. In all the areas of nuclear technology and especially the nuclear fuel cycle, chemistry research provides important inputs to the development of new processes and products and generates new understanding (eg. fuel performance, behaviour of impurities in sodium) thus providing great impetus to the development of nuclear technology. Recognising this importance of Chemistry, the Radiochemistry Laboratory (RCL) of IGCAR (then Reactor Research Centre) was conceived in the very early stages of the planning of the Centre. At a meeting held at OYC, Mumbai on August. 3, 1966 by Dr. H.N. Sethna, the then Director, Atomic Energy Establishment, Trombay, a committee was constituted to plan the Chemistry Laboratory at Kalpakkam, with Dr. M. Sundaresan of Analytical Chemistry Division, BARC and Dr. C.L. Rao, Chemistry Division, BARC as the Chemistry experts to provide inputs for the planning of the Chemistry laboratory. Interestingly, at this stage, the Chemistry Laboratory was primarily intended to be only a supporting facility for reactor technology and fuel reprocessing and it was not planned to have wide ranging chemistry programmes as was the case with BARC. It goes to the credit of Dr. C.K. Mathews who was, in the year 1970, given the responsibility for planning RCL at IGCAR that he envisaged a wide range of programmes in fuel chemistry as well as sodium chemistry to not only provide support to the fast reactor programme at Kalpakkam but also take up R&D programmes which would have a long term impact on the reactor programmes as well as fuel cycle.

The Capital project for setting up RCL was sanctioned in the year 1972 and the construction of the RCL started in late 1976. Dr. S. Raman and Sri. M.P. Mishra played a key role in coordinating the construction activities, ably supported by Sri. K.S. Naidu, and Sri. P.M. Subramanian and Sri. V.D. Marathe provided the crucial drawing and design support. The laboratory became partially operational by the year 1978 and scientific instruments including a Spectrograph, Thermal Analyser and Mass Spectrometer were commissioned during 1978-80. The launching of the R & D programme in the Radiochemistry Laboratory coincided with the organisation of a Workshop on Thermodynamics of Nuclear Materials in

January 1980, in which a large number of experts from various units of DAE participated. The highlight of this seminar was the participation of Dr. Paul E. Potter of AERE, Harwell, UK who is considered as one of the doyens of the Thermochemistry of nuclear materials. Thus, Radiochemistry Laboratory has completed 25 years of its R & D activities at Kalpakkam.

The last 25 years of activities in RCL have seen a wide range of achievements in various areas related to nuclear technology and nuclear fuel cycle. Besides the R&D activities, RCL has also provided extensive analytical support using a wide range of analytical techniques, to all the programmes in the Centre. Dr Placid Rodriguez, who took over from Dr. Mathews as Director of Chemical Group in 1995 enabled the group to maintain the momentum of activities and also enter into new areas of R & D such as novel synthesis routes for fuel materials, and also provided a focus on activities related to FBTR and FBR. I also cherish the association I had with Chemical Group as its Director from 2000 till 2004, and I have seen it mature into a world class research group with its focus firmly on the mission oriented programmes, but with increasing emphasis on developing and maintaining leadership in selected frontline areas, and expanding the range of collaborations with Chemistry groups outside DAE with a view to tap their potentials for increasing the impact of our programmes. I take pride that under the leadership of Dr. P.R.Vasudeva Rao, the laboratory is continuing to progress on the path of excellence and total committment.

The initial years of RCL coincided with the exciting period of setting up of the Fast Breeder Test Reactor at Kalpakkam. Colleagues led by Dr. C.K. Mathews (then at BARC) set up facilities at BARC for handling characterisation and studying sodium chemistry. In parallel, a group led by Dr. N.P. Bhat proceeded to set up the required facilities at Kalpakkam. The distillation method for analysing sodium samples was established in the year 1975 by this group. The trace metal analysis of sodium employing the technique of atomic absorption spectrometry was initiated in the year 1977. The chemical quality control of sodium required for charging into FBTR employing state-of-the-art analytical tools was established during 1980-81 by Dr. Bhat and Dr. T.R. Mahalingam. The Radioactive Sodium Chemistry Loop (RASCL) was designed and constructed with critical inputs from the Indo-German collaboration, and was commissioned in the year 1987. The loop has performed a variety of functions in the last 17 years, including testing of the monitors for sodium.

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Development of electrochemical meters for monitoring hydrogen, carbon and oxygen in sodium has been a highlight of the contributions of the Chemistry Group. These developments have demanded years of basic studies on various electrolyte systems, including their phase diagrams and electrical conductivity measurements. While the in-sodium hydrogen meters installed in FBTR performed well initially, they have been beset with many problems subsequently, which have been traced to electrolyte behaviour, demanding extensive studies on the phase equilibria of the molten salt systems. It is a matter of satisfaction that the hydrogen meters recently installed recently in Steam Generator Test Facility (SGTF) and Sodium Water Reaction Test Facility (SOWART) have performed well, and there is increasing confidence among the group that these would also perform well in FBTR. The work on chemical sensors has expanded to include sensors for hydrogen in argon cover gas, polymer electrolyte based sensors which can detect hydrogen in weldments, oxygen sensors for use in the Light Combat Aircraft, and $NO_x$ sensors and $H_2S$ sensors for environmental monitoring. Work on sodium chemistry has now shifted its focus to decontamination and cleaning of sodium contaminated reactor components.

Characterisation of sodium and chemistry experiments with sodium demand a highly pure inert atmosphere (containing less than one ppm of oxygen and moisture). It is a matter of pride that the inert atmosphere glove boxes for sodium handling, which were designed and fabricated indigenously, as early as 1980, have performed with exceptional merit and met the purity requirements. These facilities have enabled the Chemistry Group to generate a large volume of thermodynamic data on compounds formed by interaction of sodium with clad constituents, and in fact, comprehensive phase diagrams for many systems such as Na-Mo-O have been reported by the Group for the first time. Other areas in sodium chemistry include characterisation of samples from the radioactive primary coolant of FBTR, development of a trap for cesium in sodium and sampling systems for sodium from reactor circuits.

Work on plutonium (Pu) chemistry was initiated in RCL in the year 1983. Like studies on sodium chemistry, studying the chemistry of Pu compounds at high temperatures is a challenging task. The challenge is compounded when the work relates to air-sensitive compounds such as carbides, which has to be performed in inert atmosphere glove boxes. When

the decision to go in for the Pu rich mixed carbide fuel for FBTR was taken by the Centre, the Chemistry Group provided data on the carbon potential of the mixed carbide which provided the assurance that the fuel – clad chemical interactions will not be a source of concern for the fuel reaching high burn-up. Unique out-of-pile measurements on the thermal behaviour of the carbide fuel assured us that the fuel can be taken to desired linear ratings without the danger of centreline melting. Measurements on thermal conductivity, enthalpy, dissolution behaviour and vapor pressures have been made on fuel materials such as the mixed carbide and mixed oxide.

The Chemistry Group is among a few groups in the world which has carried out thorough investigations on the phenomenon of third phase formation in extraction of plutonium by Tri-n-Butyl Phosphate, the extractant used in Purex process for reprocessing. A good understanding of this phenomenon has contributed greatly to our design of the process flow sheet for reprocessing FBTR fuel at Lead Mini Cell (LMC). The Chemistry Group has developed a unique bifunctional resin capable of extracting uranium from a wide variety of media, and the resin has been subsequently produced in commercial domain. Novel high performance separation techniques have been developed for measuring thorium, uranium and plutonium in a variety of samples. Particularly noteworthy is the development of a Supercritical fluid extraction method for the quantitative recovery of uranium in tissue matrix, which is now being extended to extraction of plutonium.

The Chemistry Group has played a key role in the characterisation of radioactive materials. Gamma spectrometric measurements have helped in the characterisation of active sodium samples from the primary loop of FBTR. On-line alpha monitors for measurement of alpha activity and neutron collars for measuring Pu concentration in process streams have been developed and are in the process of incorporation in the reprocessing plant. A failed fuel localisation system developed at RCL has been incorporated in FBTR.

High temperature mass spectrometry has been an area of specialisation in Chemistry group. Using the Knudsen cell mass spectrometer - established for the first time in the country – a large number of systems of relevance to the fuel-clad interactions in oxide fuels, such as the tellurides of iron, nickel and chromium have been studied and phase diagrams and vaporisation behaviour established for the first time. The Chemistry Group was the first to establish the low temperature sintering of thorium dioxide employing nanocrystalline material produced through combustion synthesis. In fact, it has been demonstrated that thoria produced through this route can also be dissolved to a significant extent in nitric acid without using Hydrofluoric acid (HF).

**I have seen it mature into a world class research group with its focus firmly on the mission oriented programmes and leadership role in a few select fronterier areas**

The work programme of Chemistry Group includes many challenging areas such as pyrochemical reprocessing which involve processing of Pu fuel materials in molten salts at high temperatures for U and Pu recovery. The unique laser induced vaporisation mass spectrometry system, another first-of-its kind experimental facility, has enabled measurement of vapor pressures of thorium and uranium compounds at temperatures over 3500 K. Using this experience, an experimental facility for measuring high temperature vapor pressures over Pu fuel materials is being set up in a glove box.

The hot cell facility at RCL is a unique radiochemical facility. The hot cells are designed to house removable inert atmosphere glove boxes which are very useful in conducting studies on irradiated air-sensitive materials such as carbides and metal alloys. The hot cells were commissioned in the year 1993, by charging $UO_2$ fuel discharged from MAPS at 9300 MWd/t . The fuel was dissolved and its burn-up measured. Subsequently, the cells have handled mixed carbide fuel of FBTR discharged at 25000, 50000 and 100,000 MWd/t. Burn-up, fission gas release and dissolution behaviour measurements have been carried out on these fuels.

While pursuing R & D programmes to provide solutions to immediate problems faced in the development of fast reactor technology, the Chemistry Group has also been pursuing activities in selected frontline areas of basic research. Matrix isolation Infrared (IR) spectroscopy is an important example of such activities, set up in the laboratory in 1990. The isolation of trialkyl phosphates in an inert matrix at cryogenic temperatures has enabled recording of IR spectra of these compounds with high resolution which has been, in turn, instrumental in the determination of the conformers of these compounds. The energy ordering of the conformers were obtained with certainty through the use of a novel technique, where supersonic expansion was coupled to matrix isolation. Ab initio computations on the conformers were also performed to support the experimental work. Ligand sensitized fluorescence of lanthanides using aromatic carboxylic acids has been

shown to enhance the detection sensitivity for lanthanides in solution by orders of magnitude.

As the only comprehensive chemical facility at IGCAR, Chemistry Group has been responsible for providing analytical support to all the programmes at IGCAR. The analytical support to FBTR and reprocessing were mentioned before. Analytical support was provided to MAPS during its first commissioning in 1983 by way of isotopic analysis of boron employing Thermal Ionisation Mass Spectrometry. To meet the increasing and wide-ranging analytical requirements, the Chemistry Group has established sophisticated analytical facilities including spectrography, atomic absorption spectrophotometry and Inductively Coupled Plasma Mass spectrometry (ICP-MS). The ICP-MS has provided a large quantum of analytical support to the boron enrichment programme in the Centre.

The Chemistry Group has protected the investments on the analytical instruments that have been the tools of its growth. Technological leaps in electronics like microprocessors and PC based automation were harnessed and implemented in retrofitting the instruments so that to-day, far from falling to obsolescence, they stand enhanced in capabilities. The Thermal ionization / K-Cell Mass Spectrometers, Atomic Absorption Spectro-photometer, X-ray diffractometer and UV-VIS-IR Spectrophotometer are instances of instruments that have thus been refurbished and have completed 25 years of operation. In addition, a number of instruments have been maintained as such, over a period of more than 25 years, as exemplified by the DC ARC-AC spark Spectrograph (procured in 1978) which is still operational. Besides maintaining and refurbishing instruments, the Chemistry Group has also taken initiatives to build instruments that are specific to our special needs and hence not available commercially. A DTA developed for large volume sodium samples is an example. In tune with the development of chemical sensors, associated instrument chains were developed that employ head-on digitization and subsequent differential transmission-reception that make the traverse across large plant expanses (like the SGTF) free from noise pick up. These sensor associated instrument chains that end with micro-controller based counting have been standardized and provide the base for rapid instrumentation system development. Instrumentation for the sodium loop, Hot Cells and Lead Cells as well as the inert atmosphere glove box trains have also been developed in-house.

As the facilities at chemistry group encompass a wide range - from laboratory experiments to full fledged radiochemical facilities- skills in mechanical design are brought into play. Remote handling and mechanization have been employed in the hot cells. High integrity welding and inspection techniques have been deployed for sodium piping for the loop, active piping and for the fabrication of high vacuum chambers. Capabilities have matured in the setting up of inert atmosphere glove box tandems and is now a routine activity in Chemistry Group. Mechanisms for fuel cask alignment and charging as well as for remote cutting of fuel pins inside the cells, have been successfully designed. The setting up of the Sol-Gel facility is seeing the culmination of all these skills as also new skills like remote welding of end caps for vibro compacted fuel pins.

**As the only comprehensive chemical facility at IGCAR, Chemistry Group has been responsible for providing analytical support to all the programmes at IGCAR.**

In the recent past, the Chemistry Group has undertaken the task of establishing on a production scale the technology of elemental boron production, and initiated programmes on boron recovery from waste solutions and recycling of irradiated boron carbide. Development of sensors for FBR and advanced microsensors for environmental applications, cover gas purification system for FBR, development of Laser Induced Breakdown Spectroscopy and X-ray absorption based techniques for on-line monitoring of Pu streams in reprocessing plants, development of technology for production of Pu rich fuels and minor actinide containing fuels through sol-gel route, development of sodium bonding for metallic fuels and development of matrices for immobilising high level waste arising from fast reactor fuel reprocessing, are some of the current R & D programmes. The sampling of the programmes indicates a broad spectrum of relevant and important areas under investigation by the chemistry Group. I have no doubt in my mind that the chemistry Group will continue to play an important role in the development of fast breeder reactor technology with closed fuel cycle.

Dr. Baldev Raj
(Director)

# Testing of Prototype Control& Safety Rod Drive Mechanism

In Fast Breeder Reactor, there are two independent, fast acting, diverse, shut-down systems, each comprising of sensors, logic circuits, drive mechanisms and neutron absorber rods having boron carbide pellets. The absorber rod of the first system is called Control & Safety Rod (CSR) and that of the second system is called Diverse Safety Rod (DSR). The respective drive mechanisms are Control and Safety Rod Drive Mechanism (CSRDM) and Diverse Safety Rod Drive Mechanism (DSRDM).

The dual responsibility entrusted on CSR, i.e., to control the reactor power during normal operating condition and to shut-down the reactor by scram action during abnormal condition, necessitate highly reliable design, supported by thorough testing.

One prototype CSRDM was manufactured by an Indian Industry and prototype CSR was manufactured by NFC based on the design of IGCAR. Both were subjected to various functional tests. Initially testing was carried out in air at room temperature. Functional tests carried out for CSR in aligned and misaligned conditions (i.e., to simulate the possible misalignment of 30 mm between the axes of CSRDM and CSR in the reactor) are:

- Measurement of frictional force on mobile assembly of CSRDM and CSR with inbuilt load cells
- Measurement of minimum holding current of electromagnet
- Measurement of both gripper torque and translational torque with torque meters
- Fast drop test

The testing of CSRDM in sodium was carried out in the major sodium test facility named Large Component Test Rig (LCTR). The facility has three experimental test vessels with a total sodium hold up of 80 t. The Test Vessel – 1 of the facility was used for CSRDM testing. It of 1 m diameter and 13 m tall and holds nearly 8 $m^3$ of sodium.

After air testing, the mechanism was assembled in the sodium vessel, in aligned condition with CSR, and tested initially in hot argon at 200°C and after filling sodium, with sodium at 200°C. Subsequently the temperature of the sodium was raised by immersion


**Control and Safety Rod Drive Mechanism**

**Table 1 : Summary of Test** Results

| Recorded Parameters | For 30 mm misalignment in air | Values with 30 mm misalignment in sodium at 550°C |
|---|---|---|
| Maximum frictional force (N) during translation of Mobile Assembly of CSRDM & CSR | 280 | 315 |
| Minimum holding current (A) of electromagnet | 0.65 | 0.65 |
| Free fall time (ms) (including electromagnet response time) | 561 | 590 |
| Braking time (ms) | 192 | 21705 |
| Maximum Oil pressure (MPa) in Dashpot | 2.9 | 2.73 |

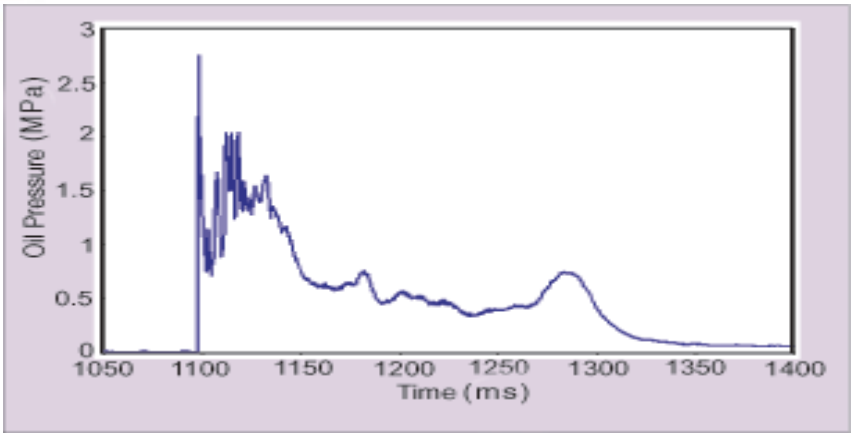



Fig.1: Dynamic Pressure of Oil in DASHPOT

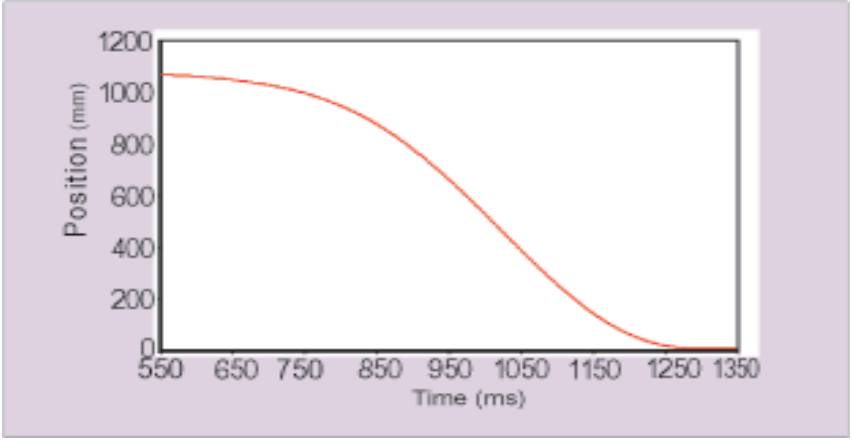



Fig.2: Displacement of CSR w.r.t. Time during SCRAM

heaters provided in LCTR up to 530°C in steps of 100°C. Performance of the CSRDM with CSR was checked at each step. The performance was satisfactory. After checking functional verification, endurance testing comprising 500 scram operations and 500 translation operations at 530°C and 60 gripper operations at 200°C were carried out.

During endurance testing, proper functioning of CSRDM & CSR was checked and ensured by recording the following parameters:

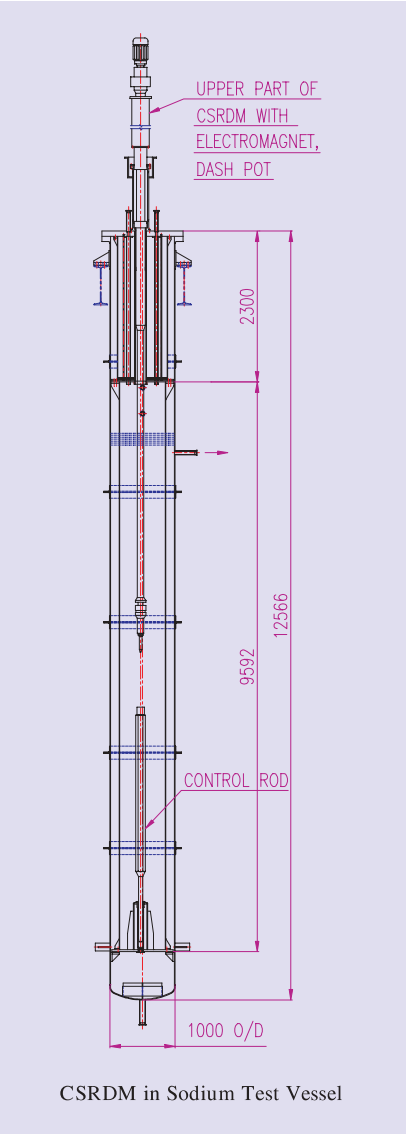
- Frictional Force
- Response Time of Electromagnet
- Free fall Time
- Braking Time
- Dynamic Pressure of oil in dashpot

The design of the CSR was modified based on analysis and on experience during testing. Air testing as outlined above was carried out with modified CSR.

Sodium testing was repeated on CSRDM with modified CSR in 30 mm misaligned condition. After functional verification tests at 200°C and at 550°C, endurance testing comprising 1093 scram operations and 1093 translation operations at 550°C and 120 gripper operations at 200°C were carried out.

Table-1 contains important parameters measured during testing in air and in sodium at 550°C.

Fig.1 shows the dynamic pressure developed in dashpot oil when the mobile assembly is decelerated by the dashpot at the end of free fall during SCRAM operation. Peak oil pressure value signifies the maximum stresses




CSRDM in Sodium Test Vessel

developed during SCRAM and it controls the peak deceleration exerted on the mobile assembly. Dashpot body is designed to withstand a pressure of 8 MPa.

Fig.2 shows the Displacement CSR recorded during the SCRAM action.

The results show that the performance of CSRDM and CSR is satisfactory. These tests have qualified CSRDM and CSR for using them in FBR.

**(Reported by CSRDM Task Force Members)**

# Development of a Decision Support System as a 'Live Tool' for Radiological Emergency Response

Estimation of radioactive dose from effluents dispersing through air route is the most challenging task in case of inadvertent discharges leading to a radiological emergency. As a regulatory and statutory requirement, a comprehensive emergency preparedness manual is already in place at all the nuclear installations in the country. Nevertheless dose assessment and forecast is necessary to aid the disaster mitigation through timely interventions for the protection of the public. A real-time simulation, assessment and forecast system for the atmospheric dispersion, if readily available on-line, would certainly provide technical input and immensely support the decision making process.

An online Radiological Emergency Response System for Kalpakkam is under development at IGCAR as part of its $X^{th}$ plan activity. This activity has gained momentum as DAE has identified IGCAR as one of the nodal centres for development of the system as a **'live tool'** for emergency response. The purpose of the tool is to assess and predict the local weather condition, the ensuing atmospheric dispersion and the consequent environmental radioactive dose for unit releases so that any time the plume distribution pattern and its forecast is available for the decision makers. Note that this provides an early warning about the affected areas and is in contrast to the current practice of estimating the same after an inadvertent event. Further, the estimated dose rates are integrated with geographical database of the site so that spatial analyses are also made available on-line to the decision making authorities. Thus the system consists of two parts namely the real-time meteorological and dispersion forecast and the development of decision support system (DSS).

## Real-time atmospheric dispersion system

In compliance with the general practice found in advanced countries as well as the Atomic Energy Regulatory Board (AERB) emergency guideline, a short range on-site assessment based on local meteorological data is made using an improved emergency code, System for Prediction of Environmental Emergency Dose Information, SPEEDI. The dose values are updated every 15min in real-time using the 50m meteorological tower data at Kalpakkam.

For the off-site long range forecast, a coupled system of a community developed Regional Mesoscale Meteorological Forecast Model (MM5) and an advanced Random Walk Particle Dispersion Model (FLEXPART) is used. The MM5 is a hydrodynamic mesoscale model and incorporates detailed physics for various processes i.e., Convection, Radiation, Micro-physics, Atmospheric Boundary Layer and Surface layer energy exchange processes. Therefore, the output products from this model covers forecast of four dimensional meteorological scalar and vector fields in a very high resolution and would be an useful tool during extreme weather events like occurrence of cyclonic system in Kalpakkam region. Hence, this model is used for forecasting the wind field in a mesoscale range of 100 km around Kalpakkam Nuclear Site. A systematic R&D study at IGCAR has shown that for complex terrain conditions like Kalpakkam, the terrain induced circulations can be simulated in a realistic manner only when representative observations are given as initial input and periodical updating of boundary conditions is done.

The synoptic scale (large scale, >100km), mesoscale(>10km) and microscale (>1km) meteorological events are dynamically cascaded in nature and hence a realistic numerical weather forecast model should consist of at least three level (scale) dynamically and numerically aligned (nested) model domains. Therefore a three-level nested grid structure with terrain following vertical co-ordinate system is used in the model and forecast is made in all the three spatial scales.

As the model is computationally very intensive, minimisation of the model run time is crucial for the emergency application. Normally, high performance computers like CRAY systems are used for executing the operational model in serial mode. Recently, with the advent of network clustering technology, similar high performance can also be achieved by a cluster of server class PCs. A parallel (MPP) version of MM5 is tested on different cluster configurations to benchmark the model run time. The parallel code has been successfully implemented and tested in single board 8 processor shared memory at IGCAR, 9 node dual Xeon Gigabit Ethernet network cluster, 8 node dual Xeon Scali pilot cluster with SCI interconnect and on 16 node dual Xeon with SCI Interconnect on the 144 node Kabru, all at The Institute of Mathematical Sciences (IMSc), Chennai. Fig.1 shows the SCALI cluster in which the dispersion system is implemented in operational mode. Table 1 shows the run time performance in shared and distributed memory clusters. A high performance cluster computer facility based on 8-node Dual Xeon is being commissioned at RSD.

In order to run the system (MM5 + FLEXPART) in an operational mode, the initial and boundary condition data (based on measurements made by India Meteorological Dept -IMD) for the weather models is to be provided as input in real time mode. The National Centre for Medium Range Weather Forecast (NCMRWF) New Delhi, collects the data from IMD through Global Telemetry System, pre-processes the data and provideds the analysis and forecast data through their T-80 global circulation forecast model. MM5 takes the analysis data as initial condition and the coarse resolution T-80 forecast as the periodic boundary condition. The model simulates 48 hr regional medium and local range meteorological fields which is then used by the dispersion model FLEXPART for the radioactive plume forecast and dose estimates. A schematic flowchart of how the on-site assessment and medium range forecast is done is shown in **Fig.2**

On an experimental basis daily


Fig.1. The SCALI cluster at IMSc., Chennai

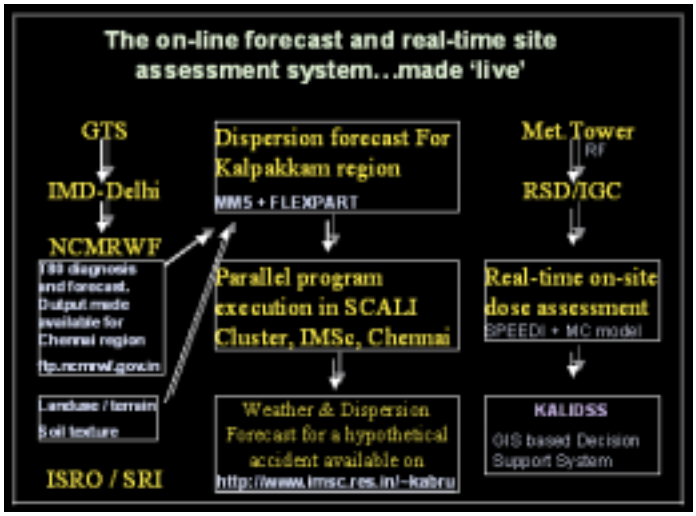



Fig.2. A flow chart showing real-time meteorological forecast and dispersion modelling system

**Table 1: Run-time performance in different computing platforms**

| Machines Available | Cluster configuration | Processor Specifications | OS and other software | MM5 model configuration | Runtime for 24 hr forecast |
|---|---|---|---|---|---|
| Xeon Server / CC, IGC | Model: BULL Express 5800 180-Ra7 Single board Shared memory SMS | 8 no. of Intel P-II Xeon 700MHz Memory: 4GB (8X512) | Linux – OS | 3 level nested domain with minimum details of physics and turbulence | 17 hr |
| Switch mode cluster IIMSc | Distributed Memory (5 nodes) | Duel Xeon At 2.4GHz, 1GB memory each. | Linux-OS with PG Fortran | -do- | 6 hr |
| Pilot Cluster / IIMSc | **Distributed Memory** (8 nodes) | Duel Xeon At 2.4GHz, 1GB memory each. | Scali – OS with PGF90 | -do- | 4 hr |
| KABRU Cluster / IIMSc | **Distributed Memory** (16 nodes) | Duel Xeon At 2.4GHz, 1GB memory each. | Scali – OS with PGF90 | -do- | 2.5 hr |

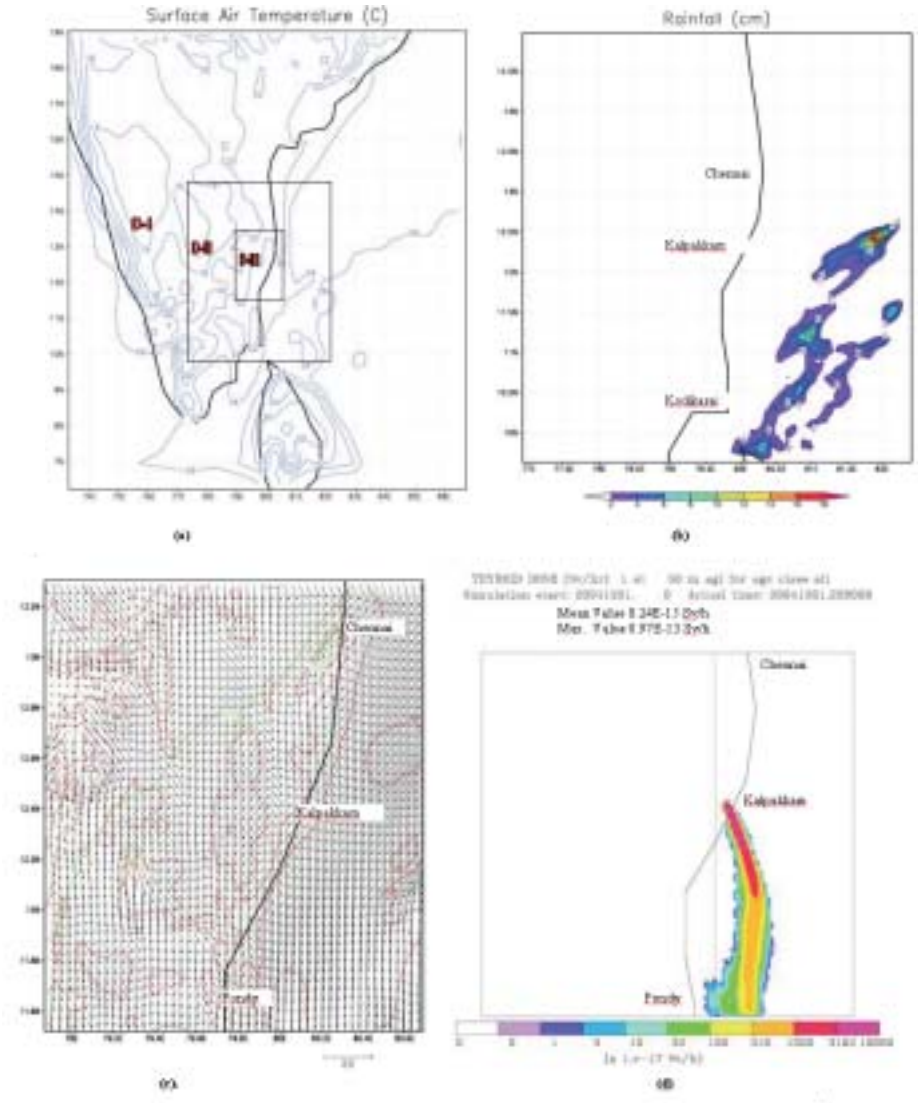



Fig.3 (a). A sample of the surface air temperature forecast in a large coarse domain D-I (18km grid resolution). Areas of two more nested domains, D-II(6km resolution) and D-III (2km resolution) are shown. (b) Rainfall forecast in a regional domain D-II. (c ) Forecast of surface wind field made in domain III (2km grid resolution). Wind velocity ($ms^{-1}$) is shown in the form of arrows and magnitude in contours (d) Thyroid dose forecast for a hypothetical release of I-131 with1 Bq/s release rate

forecast is displayed on the web page. The output displayed are: surface pressure, wind, temperature and rainfall for all the domains and the hypothetical plume dispersion in the fine domain around Kalpakkam (**Fig.3**). I-131 isotope with a release rate of 1Bq/s is considered for calculations. The dispersion output show the **simulated concentration distribution** and **Thyroid Dose(Sy)** for 48 hours**.** The operational system is tested for consistent execution and robustness at IMSc cluster computing facility. As part of validation of the modelling system, series of field experiments were conducted using state of art meteorological instruments **(Fig.4)** at Kalpakkam. Site-specific meteorological characteristics such as the variation of height of the thermal internal boundary layer (TIBL) w.r.t time of the day were estimated through these measurements. Data generated were also used to validate the MM5 predictions on typical sea breeze days. A mesoscale wind field validation experiment is proposed.

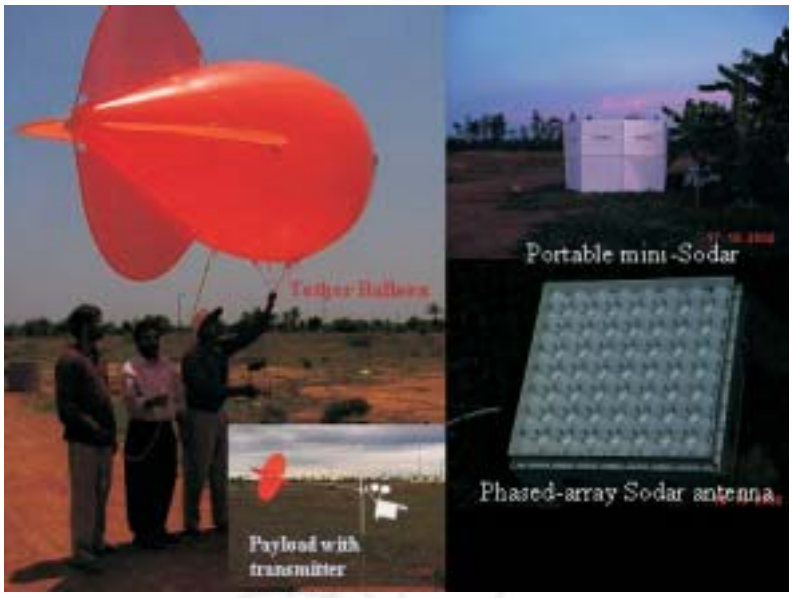



Fig.4 The state of art meteorological profilers used in validation experiment at Kalpakkam

## The design of Decision Support System

The advent and rapid growth of the state of art "3S" information technologies, namely the GIS (Geographic Information System), RS (Remote Sensing) and GPS (Geographical Positioning System) is adopted in this context to make a drastic improvement in framing the emergency preparedness procedure in a more intelligent and user friendly manner. GIS based DSS is a quick tool to identify areas of impact, counter measure supports and assimilation of on-line field measured data for re-assessment of the situation. All the spatial data base, dispersion simulation and dose forecast can be integrated with facility of querying the position of interest on site geographical maps.

Estimation and digitisation of site specific parameters were made in collaboration with Safety Research Institute (SRI), AERB using the satellite images and the SRI GIS facility. The parameters are the topography, land-use, soil texture and the cadastral digital maps with population data attributes. A case study of integrated GIS data base with forecast dose data has been attempted to develop query shells and display tools. **Fig.5** shows the dose display on the cadastral map of Kalpakkam site with boundaries of villages in Thirukalukkundram Tashil. Each village polygon is associated with data of population, availability of emergency shelter, primary health centre, transport, police station etc so that the data can be queried on-line. A comprehensive decision support system is being developed for radiological emergency management and mitigation for Kalpakkam.

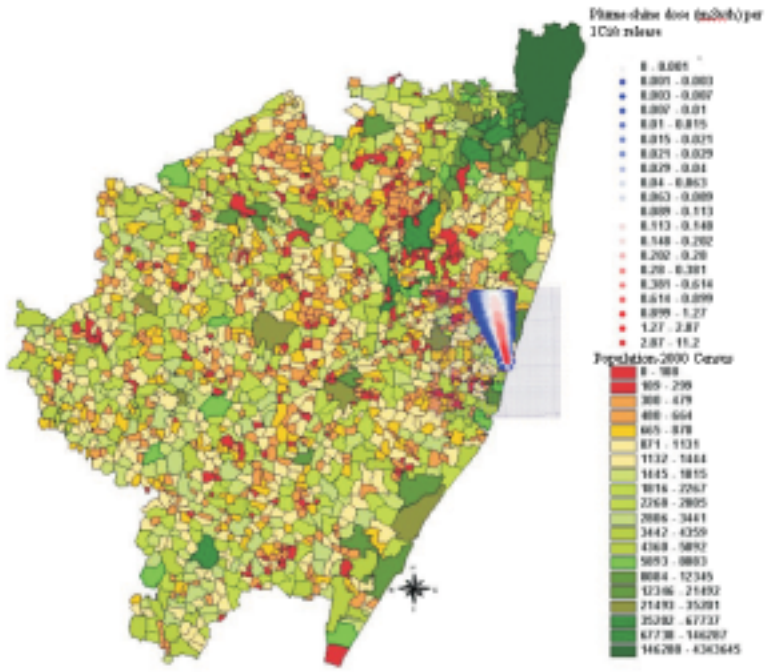


Fig.5. The Decision Support system using GIS and local cadastral database. Figure shows the village boundary map of Kanchipuram dist on which simulated air borne plume is over-laid.

**(K. M. Somayaji R. Venkatesan, C. V. Srinivas and colleagues, Radiological Impact Assessment Section, Radiological Safety Division, Safety Group)**

## Investigation of Materials under Extremely High-Pressures and High-Temperatures - Laser Heated Diamond Anvil Cell Facility

The Diamond Anvil Cell (DAC) is a *tool par excellence* to subject matter to very high static pressures. High strength of the diamonds coupled with their excellent transmittance to almost the entire electromagnetic spectrum has led to extensive *in situ* studies on a myriad of pressure induced phenomena in materials using techniques such as the x-ray diffraction, Raman and Brillouin spectroscopy, luminescence spectroscopy, Mossbauer spectroscopy, etc. up to several megabars. This wide-range transmittance of diamonds can be exploited to focus high power IR laser beams on to the sample squeezed in the DAC, thereby subjecting it simultaneously to very high temperatures of over 5000 K and pressures of over many megabars. This technique, called the Laser Heated Diamond Anvil Cell (LHDAC), has been known for more than a decade, and in recent years, it is emerging as a preferred route for investigating materials and synthesizing novel phases in the hitherto unexplored P-T region. This technique provides an unique opportunity of simulating, in the laboratory, the extreme environments such as those existing in planetary interiors. The idea behind the LHDAC technique is that at such extreme conditions, the nature of the chemical bonding in elements changes and the chemical reactivities generally increase such that direct elemental reaction between even inert species becomes possible leading to the formation of novel and exotic phases. Synthesis of nitrides of C, B, Si and Ge that are expected to rival diamond in terms of hardness is currently one

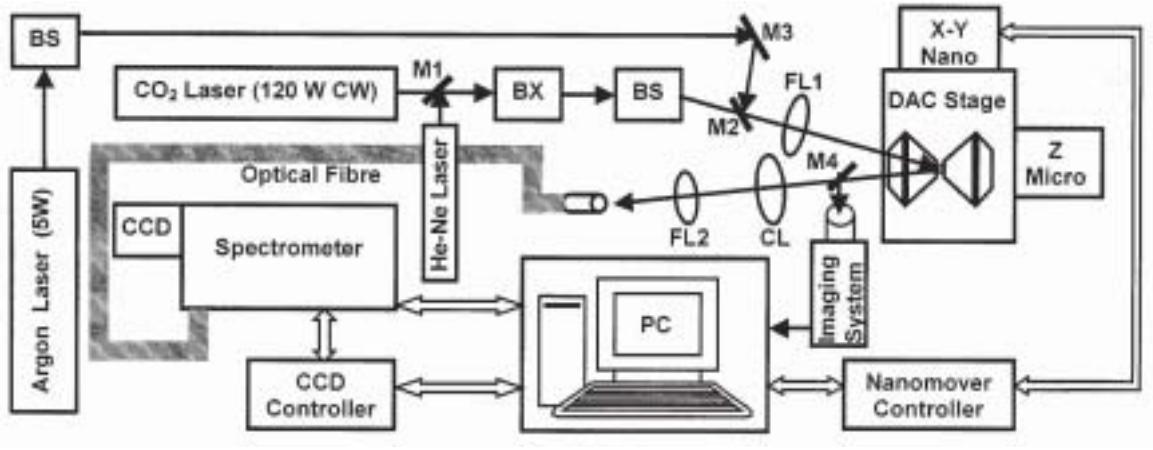



Fig 1: Schematic of the LHDAC set-up; M1, M2, etc.: Mirrors; BS: Beam Steerer; BX: Beam Expander; FL1 and FL2: Focussing Lenses; CL: Collecting Lens;

of the frontline problems addressed by the LHDAC researchers. Other applications of the LHDAC include investigation of melting phenomena and structural transitions in a variety of materials.

At Materials Science Division (MSD), a state-of-the-art LHDAC facility has been setup to address some of the above applications. The challenge lay in heating the ultra tiny sample (~75 μm diameter) that is "squeezed" between the two diamond anvils to very high-temperatures using the invisible high power IR laser beam without causing any damage to the diamonds and other supporting materials.

A schematic and photograph of the LHDAC facility we have set-up are shown in figures 1 and 2 respectively. An indigenously developed DAC, a 120 W CW $CO_2$ laser (λ=10.6 μm), and a X-Y Nanomotion system are the essential constituents of this set-up. Here, samples can be subjected to pressures of up to a megabar and temperatures in excess of ~5000 K. Some of the salient aspects of this set-up are:

***IR Optics:*** A red He-Ne laser beam is first made to traverse the same path as the $CO_2$ laser beam. Alignment of the $CO_2$ laser compatible optical components like the beam expander (BX), beam steerer (BS)and focusing lens (FL1) is then done with the visible He-Ne laser. Final focusing of the $CO_2$ beam (spot size ~40 μm) is achieved at the centre of the sample inside the DAC by manipulating the beam as well as the DAC XYZ stage with a PC-controlled nanomover system.

***Nanomover System:*** In heating experiments with the LHDAC facility, a critical requirement is that the focussed IR laser beam should fall exactly on the sample squeezed inside the DAC. Otherwise there is a risk of damage to the diamond anvils and other supporting materials leading to failure of the DAC. Further, various regions of the sample have to be exposed to the focal spot to have uniform heating. In order to achieve the above, nanomotion systems (X-Y Nano) are being used in our LHDAC facility. The DAC is mounted on a XYZ stage, in which motion along the X-Y directions (beam direction: Z) is brought about by two Nanomovers with which the DAC can be moved in steps, of sizes ranging from 10 nm up to 2 mm, with respect to the focussed laser spot.

An in-house developed control software using LABVIEW is used for operating the above nanomotion system. RS-232C interface is used to link the nanomover controller to the

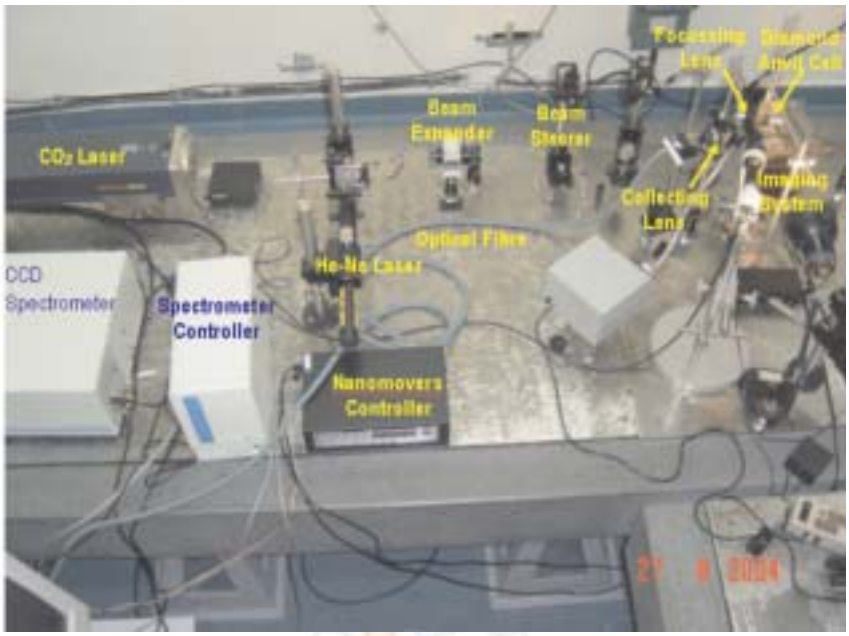



Fig.2: Photograph of the set-up; All components, including the lasers are mounted on a granite table located on a special foundation, structurally isolated from the rest of the building to minimize vibrations.

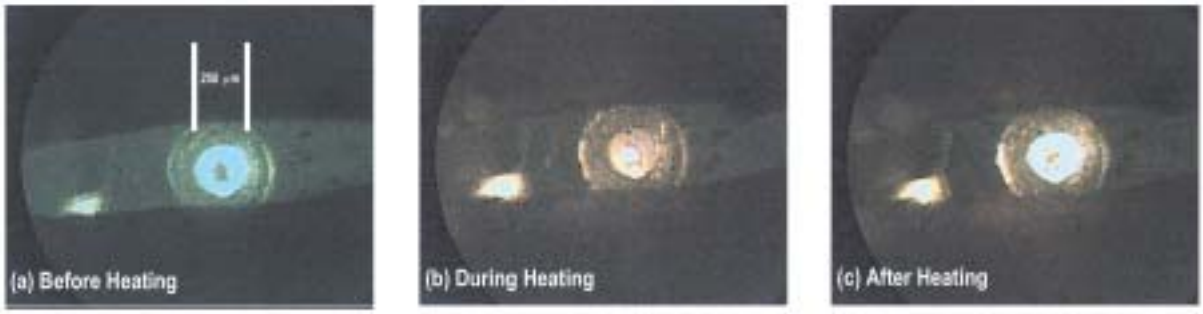



Fig. 3 : Heating of Graphite with the LHDAC set=up of P~14 GPa: (a) before heating; (b) during heating by $CO_2$ laser and (c) after heating. (Webcam Pictures)

PC. The key feature of this software is a virtual joystick, constructed out of a complex network of Boolean "soft" switches, capable of controlling the X and Y nanomovers simultaneously or separately as the situation may demand.

***Imaging System:*** A simple cost-effective remote imaging system was implemented in our set-up by coupling a webcamera to a 100X microscope. This enabled us to achieve good real-time imaging and thereby better focussing of the IR laser beam on to the sample. Further, remote imaging of the hot sample greatly reduces any eye-hazard to the personnel. Recently, we have replaced this with a CCD-based imaging system that offers a higher resolution (640 x 480 dpi) and maximum magnification of 70X (optical) and 220X (video PC) with a 1.5X objective.

***Spectrometer****:* Temperature and pressure are the two crucial parameters that have to be measured in a LHDAC facility. The former has to be done by recording the black-body radiation spectrum of the hot, microscopic sample and utilizing Planck's law. Pressure, on the other hand, has to be measured using the well-known ruby fluorescence method. An $Ar^+$-laser (5 W; M/s Coherent, US) has been installed in our LHDAC facility for exciting fluorescence from the small ruby chip kept *in situ* along with the sample to be heated. This laser is also aligned in the same optical path as the $CO_2$ laser beam. In order to detect the ruby fluorescence as well as the black-body emission spectra from the hot sample, we have installed a $LN_2$- cooled CCD based spectrometer. This spectrometer has two entry ports, through which signals from the pressure calibration and laser-heating set-ups can be fed independently, if needed, by means of optical fibres.

In order to demonstrate the capability of our facility, we took up the problem of direct conversion of graphite to a "diamond-like" phase. A high purity graphite chip (linear dimension ~75 μm), sandwiched between two KBr layers was loaded in the DAC. The KBr layers were used to thermally insulate the sample from the diamond anvils as also provide optical windows. We found that at a pressure of ~15 GPa and at a laser power of ~15 Watts, exothermic reaction characterised by flashes of very bright light got initiated. The temperature was estimated to be ~2000 K. Using the nanomovers we rastered the sample across the $CO_2$ laser beam. After the heating event lasting for nearly 45 minutes, we found that the entire graphite chip had become translucent to light, indicating formation of a new transparent phase (Fig. 3c). Characterisation experiments like Raman spectroscopy and SEM are presently being pursued to determine if the new phase is indeed diamond.

To summarise, a LHDAC facility has been successfully setup to investigate materials behaviour at very high pressures and temperatures. It was gratifying to note that even after ~3 hours of continuous heating with the high power laser we did not observe any damage to the DAC, demonstrating the high level of perfection in the optics we have designed and set-up. The present set-up will be utilized chiefly to study insulating samples. We are now in the process of integrating a 30 W CW Nd:YAG laser ($\lambda$ = 1.06 μm) in our facility to study metallic samples. A holographic notch filter will also be installed soon in the facility to perform Raman spectroscopy of the laser-heated samples.

Our immediate target will be to attempt high pressure - high temperature synthesis of superhard materials involving low Z elements such as C,N,B,Li etc. and also the synthesis of carbides, nitrides oxides of the transition metals. Subsequently, after perfecting the temperature measurement by spectro-radiometric technique, exploration of the melting curves of materials of interest will be carried out. In future, after commissioning of the INDUS-II synchrotron facility at Indore, in-situ x-ray diffraction studies under high pressure & high temperature using the LHDAC will be attempted.

**(N. Subramanian, N. V. Chandra Shekar, N. R. Sanjay Kumar, and P. Ch. Sahu, MSD)**

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# Instrumented Fuel Subassembly for Flow Induced Vibration Studies

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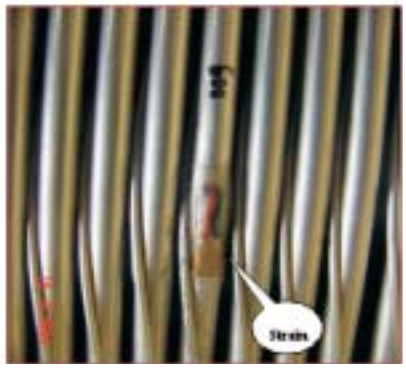
Fast Breeder Reactor (FBR) fuel subassembly consists of 217 fuel pins arranged in 17 rows and vertically held in the form of bundle within a hexagonal wrapper tube. The pins are separated by spacer wires wound around the pins helically. The coolant sodium flows from the bottom of the subassembly to top and it is in a turbulent regime in the bundle area. The nominal flow through the central subassembly is 36Kg/s. This turbulent flow can excite flow-induced vibration of fuel pins. The vibration amplitude will depend upon the support provided by the spacer wire and other parameters like mass, stiffness, and damping. These vibrations can cause failure of the fuel element clad tubes from fatigue, wear and vibration induced fretting. Excessive vibration will cause reactivity noise, fatigue or rattling. Analytical modeling of these vibrations are extremely difficult because of the complex geometry and the time varying boundary conditions present in the spiral wrap type fuel design. Because of the limitations of the analytical model it is often necessary to predict turbulence induced vibration using empirical relations such as Burgreen and Paidousis correlations. However to get more accurate evaluation of the pin vibration of PFBR subassembly, it is necessary to carry out measurements on a full scale dummy subassembly in water test rigs.



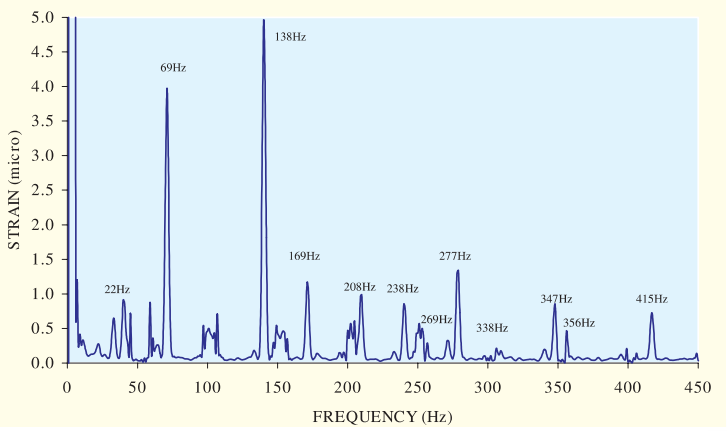



Fig. 1 : Vibration spectra of fuel pin (Flow-184 Cu.m/h)

During manufacturing of dummy subassembly at NFC, strain gauges were installed on fuel pins. However while conducting FIV experiments in water it was found that some strain gauges were peeled off from the fuel pin surface. Hence re-instrumentation work of subassembly was carried out.

Eighteen pins were instrumented with foil type strain gauge. It is necessary to measure vibration in two perpendicular directions. Due to difficulties in installing two strain gauges on one fuel pin and routing the signal cables, installation of two orthogonal gauges on two adjacent fuel pins were done at the same elevation. For these measurements,

**Table 1: Analytical and Experimental Modal Frequenceis of Fuel Pins and Subassembly**

| Modal frequencies of subassembly and pin (Analytical) (Hz) | | Measured modal frequencies of Subassembly | Measured vibration frequencies of pins from FIV test (Hz)( in water) (in air) |
|---|---|---|---|
| Subassembly ( in air) | Fuel pin (in water) | | |
| 4.6 | 76.70 | 4.44 | 69 |
| 28.4 | 238.50 | 19.11 | 69 |
| 77.75 | 257.80 | 20.23 | 138 |
| 148.18 | 278.90 | 24.49 | 202 |
| 181.6 | 286.40 | 33.96 | 238 |
| 236.87 | 289.69 | 58.43 | 269 |
| 340.6 | 309.00 | 76.18 | 277 |
| 458.29 | 349.00 | 89.02 | 338 |

pins are selected at the middle of the bundle, near corner and near hexcan and the measurement spans are distributed to bottom, middle and top of fuel bundle. The instrumented fuel pins are packed with SS grooved pellets for routing of strain gauge cables and other pins are packed with solid SS pellets simulating fuel pellets. There are in total 54 nos of grooved pellets packed inside the fuel pins out of which 53 nos are 30mm length and one is 15 mm length.

The dummy subassembly is provided a flange connection with "O" ring at the end of hexcan. This arrangement will help to remove the hexcan for installation of strain gauge on fuel pins. The dummy sub assembly was fixed in a structure and top portion of hexcan was removed. While removing each rows of fuel pin, marking, numbering and directions of all pins and rows were done in order to facilitate for identification and reassembly. SS grooved pellets were removed from the pin and pellets and pin were thoroughly cleaned with acetone. Foil type strain gauge was pasted over the pin surface at required elevation using anabond and strain gauge cable was routed through inside of the clad tube. Grooved pellets were packed inside the clad tube and strain gauge cable was routed through the waterproof sleeve and top end of clad tube was sealed with araldite. Strain gauge was also covered with two layers of araldite for waterproof. Similar installation method was followed for all instrumented pins. Numbering of pins was done with ferrules at end of each strain gauge cables. Bottom portion of a dummy subassembly was fixed in a structure and all 17 rows of pins were reassembled in a guide. Fuel pins were clamped together at three locations. While lowering top portion of hexcan, strain gauge cables were routed out through the 9 nozzles, provided on the hexcan and simultaneously all the three clamps were removed. The top and bottom portions of hexcan were bolted together. Araldite and M-seal were applied over the nozzle for leak tightness. Finally the insulation and resistance values of the each strain gauge were checked for its healthiness and it was found satisfactory. One accelerometer was also pasted over middle of the pin surface and its cable was routed out through the threaded nozzle. Leak tight sealant was applied over the nozzle. The instrumented subassembly was erected in a water test rig and all strain gauge cable and accelerometer cable with waterproof sleeves were routed out through the flange-nozzle connection provided in the test section. The insulation and resistance values of the each strain gauge were checked again for its healthiness and it was found satisfactory.

Preliminary measurement of fuel pin vibration was conducted in water for flow upto 184 Cu.m/h. (120% of nominal flow) The simulation criterion from sodium to water is established from the Burgreen correlation for fuel pin vibration. The vibration spectra were recorded using Pulse software, which is capable of estimating Fast Fourier transformation and Power spectral density analysis. Fig-1 shows the measured vibration spectra of fuel pin at 184 Cu.m/h. Measured vibration frequencies of pins from FIV testing and modal frequencies of subassembly in air and analytical values of modal frequencies are shown in Table-1. Some additional model frequencies in the Experimental results are observed because the support conditions assumed for analysis is fixed, whereas in FBR, Subassembly is a free standing structure in a subassembly sleeve and can undergo both lateral and rotational modes of vibration. Subassembly is a complex structure consisting of outer hexcan and pin bundle assembly and hence vibration spectra can show frequencies due to the excitation of modal frequencies of pin bundle and hexcan separately and/or due to their combined effect. The predominant frequencies of 69 Hz and 138 Hz in Fig-1 correspond to modal frequencies of subassembly as a whole, vibrating in a cantilever mode. The higher frequencies from the pin bundle are also seen in the spectra, however their levels are not significant. The over all vibration level of fuel pins estimated from the vibration spectra (Fig-1) is also not significant (around 7 micro strain). The permissible vibration in fuel pin from fatigue consideration is 94 microstrain and from fretting consideration is 250 microstrain. From the experimental results it is found that the design of fuel pin bundle is adequate with respect to flow induced vibration phenomenon.

**(M. Anandaraj and colleagues, Vibration & Noise Analysis Section, Separation Technology & Hydraulics Division, Fast Reactor Technology Group)**

# Experiences during Testing of Transfer Arm in Air

Transfer arm will be used for in-vessel fuel handling in FBR. The schematic of Transfer Arm (TA) is shown in Fig. 1. Transfer arm manufactured by an Indian industry was erected on Large Component Test Rig (LCTR) in Hall-3. The basic movements in TA are guide tube hoisting, gripper hoisting, fingers actuation, TA rotation and auto orientation of the Sub-Assembly (SA).

Each operation of TA was tested independently for 210 cycles in air. Subsequently sequential testing of TA, which includes holding the Sub Assembly (SA), lifting, TA rotation, lowering at vacant position and SA full insertion check up was carried out for 25 times.

During testing in air, the gripper hoisting wire rope slipped out of the groove of its drum and got damaged. The cause was examined. The delay in stopping the gripper hoist motor by low-tension limit switch caused the slackness in the wire rope and resulted slipping of the wire rope from the groove. The wire rope was replaced with a new wire rope. A guard for preventing the wire rope coming out off its groove during low tension was designed and installed. The thimble joint between the wire rope and gripper was modified to socket joint. This gave a gain in the upward travel of 70 mm, which was required to achieve the upper limit specified in the gripper hoisting. After incorporating the above modifications, the gripper hoisting operation was carried out for about 50 times successfully. After few operations of fingers actuation, the Inner Tube (IT) was found to be jamming in Outer Tube (OT) due to the presence of multiple guides between IT and OT, which affected fingers actuation.

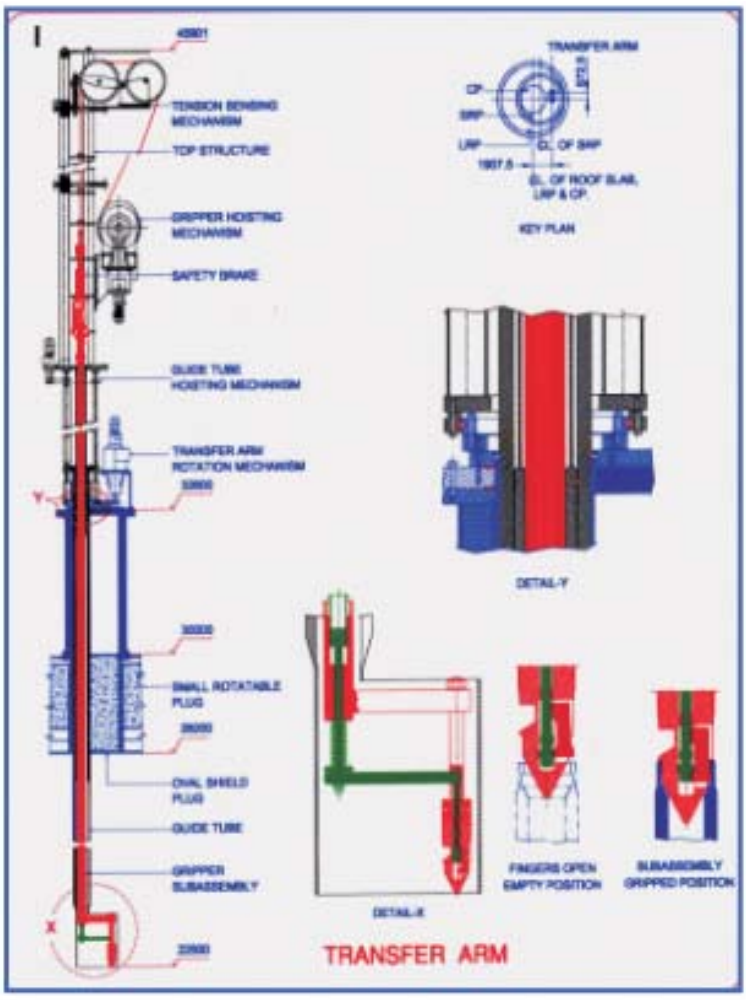



Fig 1: General Assembly of Transfer arm

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Nilayendra Chakraborty (DOB – 03/01/1972) obtained his B.E degree (Mechanical Engineering) from Bengal Engineering college in 1996. He joined IGCAR directly as SO/C in February 2002.

A mock up IT with carbon steel material with reduced diameter was introduced after removing the original inner tube. This had only two guides, one at the top and the other at the bottom. Fingers actuation with the mock up IT was smooth. Following the same design, a new stainless steel inner tube similar to the mock up IT was fabricated with required shielding to serve in reactor and installed. Additionally to reduce the jerks in the fingers actuation, the actuator rod was modified to achieve adequate clearances. With the above modifications fingers actuation was demonstrated successfully for a total of 210 cycles.

Fig. 2: Auto Orientation Test Set-up

Fig. 3: Handling of Sub-Assembly by Transfer Arm

While inserting into the vacant position by TA, the SA has to be oriented automatically to match with the hexagonal opening. For that, 2 taper roller bearings are provided in the gripper assembly. Each face of the SA is provided with V- shaped slots at the top and matching projections at the bottom. To test the auto orientation, neighboring six SAs are required. A test set up (Fig-2) was fabricated, which simulates heads of the neighbouring 6 SAs surrounding the vacant position. SA was inserted into the vacant position in the test set up and the auto orientation of the SA was checked and it is found smooth. Further, six neighboring SAs were positioned (Fig-3) surrounding the SA. The six SAs were held together by a clamp and the lifting of the central SA was demonstrated.

After 150 number of operations, the downward movement of the gripper by its self weight (7000 N) was not smooth. Scoring marks are observed on the surface of OT. The cause was examined and modifications are proposed to solve the above problem. After incorporating the modifications, the TA will be re-assembled in Test Vessel-2 of LCTR and retested for its functionality in air. Subsequently testing will be carried out in sodium at reactor operating and fuel handling conditions. After successful completion of these tests, the Transfer Arm is qualified to serve in the reactor.

**(S.C.S.P. Kumar Krovvidi & Nilayendra Chakraborty and Colleagues, Large Component Testing Section, Sodium Technology Group, Fast Reactor Technology Group)**

# Awards & Honours

Congratulations

- Dr. Baldev Raj has been awarded the *Lifetime Achievement Award* for the year 2004 by the Indian Welding Society for his contributions to the field of Welding, during February 2005.
- Dr. Baldev Raj has also been awarded the prestigious *Jaeger Lecture Award by the International Institute of Welding.* The award was given on February 16, 2005 by the President, International Institute of Welding during the International Welding Congress at Mumbai. Dr. Baldev Raj is the first Indian to receive this award in recognition of his research as well as the impact of his contribution in the area of Welding Science & Technology.
- The paper entitled *"Development of activated Flux for Tungsten Inert Gas Welding of 304L(N) Austenitic Stainless Steel"* by V. Ramasubbu, S.K. Albert, A.K. Bhaduri and S.K. Ray was awarded the *H.D. Govindaraj Memorial Award* for the Best Paper on Research & Development.
- The paper entitled *"High Temperature Performance of Steam Generator Transition Joints between modified 9Cr-1Mo Steel and Alloy 800"* by M. Sireesha (IIT-M), S. Sundaresan (IIT-M) and S.K. Albert was awarded the *KCP Award* for the First Best paper on Fabrication

The above two awards were presented during the inaugural ceremony of International Welding Congress (IIW-IC-2005), Mumbai on February 16th 2005.

Chairman, Editorial Committee : Dr. Baldev Raj, Advisory Member : Shri S.C. Chetal.
Members : Dr. P.R. Vasudeva Rao, Dr. K. Govinda Rajan, Shri. V.S. Krishnamachari, Shri. M. Somasekharan and Dr. G. Amarendra.
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