BARC HIGHLIGHTS

ELECTRONICS, INSTRUMENTATION AND COMPUTERS

भारत सरकार
Government of India

भाभा परमाणु अनुसंधान केंद्र
BHABHA ATOMIC RESEARCH CENTRE

स्वर्ण जयंती वर्ष
GOLDEN JUBILEE YEAR
2006-2007

For further details contact:

R. K. Patil
Associate Director, Electronics & Instrumentation Group
Bhabha Atomic Research Centre,
Trombay, Mumbai - 400 085, India.

E mail : rkpatil@barc.gov.in

Published by :

Dr. Vijai Kumar
Associate Director, Knowledge Management Group and
Head, Scientific Information Resource Division,
Bhabha Atomic Research Centre, Trombay, Mumbai - 400 085, India.

E mail: vijai@barc.gov.in

FOREWORD

Bhabha Atomic Research Centre (BARC) is celebrating its golden jubilee year during 2006-07. On 20th January, 1956, Pandit Jawaharlal Nehru formally inaugurated the Atomic Energy Establishment Trombay (AEET), which is renamed as Bhabha Atomic Research Centre (BARC) on January 22, 1967. As a premier R & D centre of the Department of Atomic Energy (DAE), BARC has a mandate to provide R & D support to the nuclear power programme, to pursue all activities related to nuclear fuel cycle, to operate research reactors for supporting neutron beam research and supplying radioisotopes for various applications, to conduct frontline basic research in physical, chemical, biological and engineering sciences all of which leading towards improving quality of life of our people. The achievements BARC has made over the last 50 years are well known not only to the scientific community in the country but also to our people at large. Scientific achievements made by this premier research centre are well documented in various publications of DAE including a series named "BARC Highlights". During this golden jubilee year, we have made an effort to bring out some glimpses of recent research and development accomplishments in the form of 8 volumes, highlighting the following areas:

1. Nuclear Fuel Cycle
2. Physical Sciences
3. Chemical Science and Engineering
4. Materials Science and Engineering
5. Life Sciences
6. Reactor Technology and Engineering
7. Electronics, Instrumentation and Computers
8. Environmental Science and Engineering

These volumes will showcase the latest work in the aforementioned areas and will demonstrate how each of these, is directed towards achieving the overall goal of using nuclear energy for the benefit of our people.

Nuclear energy programme in India has now reached a level of maturity. Today, India is self-sufficient in building nuclear power stations of 540 MWe capacities and has gained mastery over the entire fuel cycle. We are at the threshold of entering the second stage of nuclear power programme, in which a rapid growth in installed capacity is expected through the fast reactor programme. In the area of basic research in science and engineering, BARC has been maintaining a leading position both in national and international scenario. One of the strongest points of basic research in BARC lies in its capability in building sophisticated research facilities in-house. The core competence of the scientists and engineers in our centre covers a very wide range as is reflected in the 8 companion volumes being released on the occasion of the golden jubilee year.

This volume of 'BARC highlights' is dedicated to Electronics, Instrumentation & Computers. Development of remotely - operated and controlled instruments and robots for carrying out tasks in hazardous environments, railways loco safety devices, inspection gauges for the underground oil pipe lines, acoustic emission based systems for inspection of reactor structures and components, ultrasonic - based NDT techniques, Application Specific Integrated Circuits (ASICS) and medical electronics, among others are the highlights of this volume.

Setting up, operation and maintenance of nuclear reactors – both power reactors for commercial electricity generation and research reactors for R & D activities - are the vital prerequisites for the success of the atomic energy programme of the country. Control and instrumentation aspects of these nuclear reactors are integral parts of this programme. BARC has accepted these challenges and successfully developed various sophisticated control instruments for the Indian Nuclear Reactors. Design and development of new generation computer controlled, safety critical C & I systems having latest technologies for 540 MWe reactors at Tarapur are the major highlights of this program. C & I of Advanced Heavy Water Reactor (AHWR) and Prototype Fast Breeder Reactor (PFBR) are also discussed. Development of electron accelerators and their control electronics constitute a major R & D program of BARC. Applications of accelerators in areas of radiation processing of bulk polymers, cross linking of plastic, generation of flash X-rays, pulsed neutron and ion sources etc. has got immense industrial importance. BARC expertise in control electronics finds extensive collaborative programs with national level institutions and international organizations like CERN and Australian National University (ANU).

Radiation monitoring equipment, instruments and radiation detectors are developed in BARC as a direct out come of its own research activities in the areas of plants, personnel and surrounding environmental monitoring. Continuous upgradation of the instruments and

monitors are carried out to meet any radiation emergencies and to augment the current radiological surveillance and security. Several types of radiation detectors such as gas filled detectors, self powered neutron detectors and preshower silicon detectors for CERN have been developed to meet special needs of reactor and other experimental programs.

Quick, safe and efficient information dissemination amongst the working scientific fraternity in BARC and outside is achieved mainly through in-house developed 128 node ANUPAM supercomputer, graphics and visualization software and grid software. The availability of supercomputing facilities has further enhanced the scientific visualisation, information processing and information exchange in all fields of the institutional activities. A well established network of information highways with adequate physical and cyber security includes development of biometric based systems, encryption technology, secure management of computer networks and Internet services etc.

The present volume will provide an outline of the current work and various accomplishments made in the area of Electronics, Instrumentation and Computers in BARC.

Srikumar Banerjee
Director

PREFACE

BARC is a premiere organization engaged in research and development on a wide range of science and technology areas relevant to nuclear power, nuclear fuel cycle, applications of nuclear and other spin-off technologies and basic sciences.

This volume includes highlights of R&D work in Electronics, Instrumentation and Computers. It has been a complex task to bring out a compact volume describing major highlights of work in this vast area. The work presented here has been carried out over the last three to four years. Some of it represents work in the frontier areas of contemporary relevance while lot of other work is indigenous technology development relevant to programs of a multi-disciplinary organization like BARC and represents our dedication to self-reliance in advanced technology areas.

BARC's research and development program in Electronics, Instrumentation and Computers has made spectacular progress in recent years and made solid contributions to areas such as control and instrumentation systems for nuclear reactors, computers and software, accelerator and electron beam technology, radiation detectors and applications, robotics and remote handling, electronics standardization and ASICS and has provided crucial support to research in basic sciences.

Notable achievements in recent times have been the successful development and commissioning of a large number of control and instrumentation systems at India's first 540 MWe pressurized heavy water reactor at Tarapur, Maharashtra. Electron beam machines operating over a wide range of power levels, from a few kilowatts to a few hundreds of kilowatts, have been indigenously developed at BARC for welding, melting and non-thermal processing. A number of advanced instruments using state-of-the-art technology have been developed for small laboratory experiments to accelerator based big experiments under various DAE programs for research in basic sciences. As a result of years of R & D efforts, BARC has developed indigenous capability in the development of state-of-the-art radiation detectors and nuclear electronic systems. More than 4000 scientists and engineers working on various advanced R & D programs at BARC are extensively using computers for meeting their requirements of supercomputing, general scientific computing, scientific visualization, information processing and information exchange. Grid Computing is expected to meet large computing requirements in coming years. BARC is participating in an international effort to develop Grid software with the European Organization for Nuclear Research (CERN). Although the primary goal of our programs in Electronics, Instrumentation and Computers is to meet requirements of DAE, the technologies developed here have also been used in other sectors e.g. Instrumented Pipe Inspection Gauging (IPIG) equipment developed for IOC and Train Wheel Detection Sensors developed for Konkan Railway.

A major part of the work reported here has been published in journals and peer-reviewed conference proceedings, references of which have been included. For technology development items contact persons have been indicated who can provide further information. It is hoped that this volume will be of interest to engineers, academicians and other professionals in the area of Electronics, Instrumentation and Computers.

R. K. Patil

ELECTRONICS, INSTRUMENTATION & COMPUTERS

CONTENTS

1. CONTROL AND INSTRUMENTATION FOR NUCLEAR REACTORS

INTRODUCTION

BARC has all along been involved in the development of Control and Instrumentation (C & I) systems for power reactors. During recent years the centre was engaged in development of new C & I systems for the 540 MWe reactors TAPS 3 & 4. For improved reliability and maintainability the reactor protection system has been fully computerized for the first time. The 540 MWe reactors are larger than the 220 MWe units hitherto built and hence the number of input-output signals and reactivity control devices required were an order larger, necessitating new multinodal system architecture for the Reactor Regulating System (RRS) featuring use of digital communication for the first time in a safety related system. A new type of reactivity control device called Liquid Zone Control Compartment has also been developed for the 540 MWe reactors. The Process Control System at TAPS 3 & 4 features use of optical fiber links for digital data communication. For TAPS 3 & 4 a new function, viz., automatic reactor set-back (reduction of reactor power output) has been incorporated in Coolant Channel Temperature Monitoring System.

A strong R & D program is underway for development of C & I for Advanced Heavy Water Reactor (AHWR) and Prototype Fast Breeder Reactor (PFBR). The R & D program also supports existing research reactors for replacement of aging control and instrumentation systems. Development of sensors, standardized digital hardware and software is being carried out for future C & I systems.

Software reliability is an important aspect of computer-based C & I systems performing safety critical functions in a nuclear power plant. The activities in this area encompass application of advanced verification & validation (V & V) techniques such as static analysis, assertion-based verification of safety critical software, development of V & V tools based on formal techniques, application of formal techniques of verification, standards and guidelines for development of safety critical software.

Highlights of above mentioned systems and some other new developments follow:

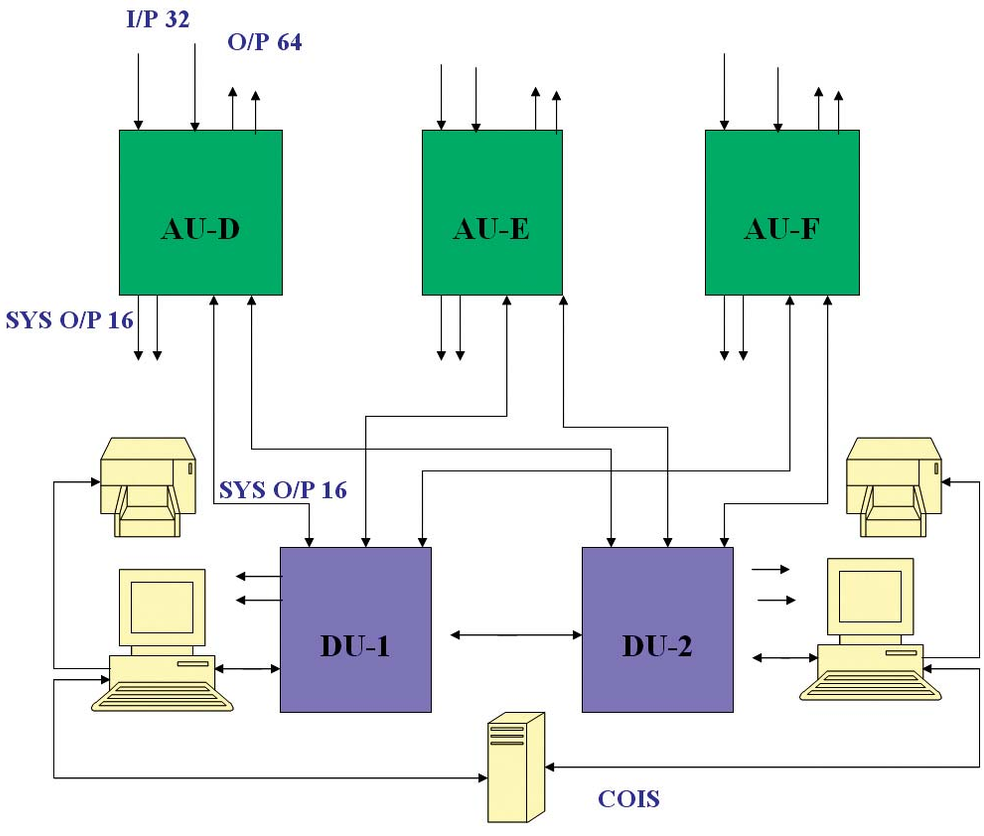
1.1 CONTROL AND INSTRUMENTATION (C&I) FOR PRESSURISED HEAVY WATER REACTORS (PHWRs)

■ Computerized Reactor Protection System for TAPS 3 & 4

Reactor Protection System (RPS) is the sensing and command processing part of the reactor shutdown system. TAPS 3 & 4 are the first reactors to have their RPS fully computerized for high reliability and maintainability. The RPS handles 32 analog trip inputs, compares the signal values with the configurable set points and generates trip outputs. The system is configured as triplicated Alarm Units (AUs) to handle the three channel inputs and generate trip outputs. Redundant Display Units (DUs), which communicate with each other on isolated serial links for exchanging data, provide operator interface to the system. The trip generating function is independent of display unit or the communication. Extensive diagnostic routines monitor the system and on detection of any failure the outputs are driven to the safe state of trip condition.

The software has been developed through proper lifecycle as required for a Class-IA system, following IEC-880 and AERB D-25 guidelines. The software has been subjected to rigorous Verification and Validation (V & V) by an independent regulatory agency.

B.B. Biswas <bbbiswas@barc.gov.in>



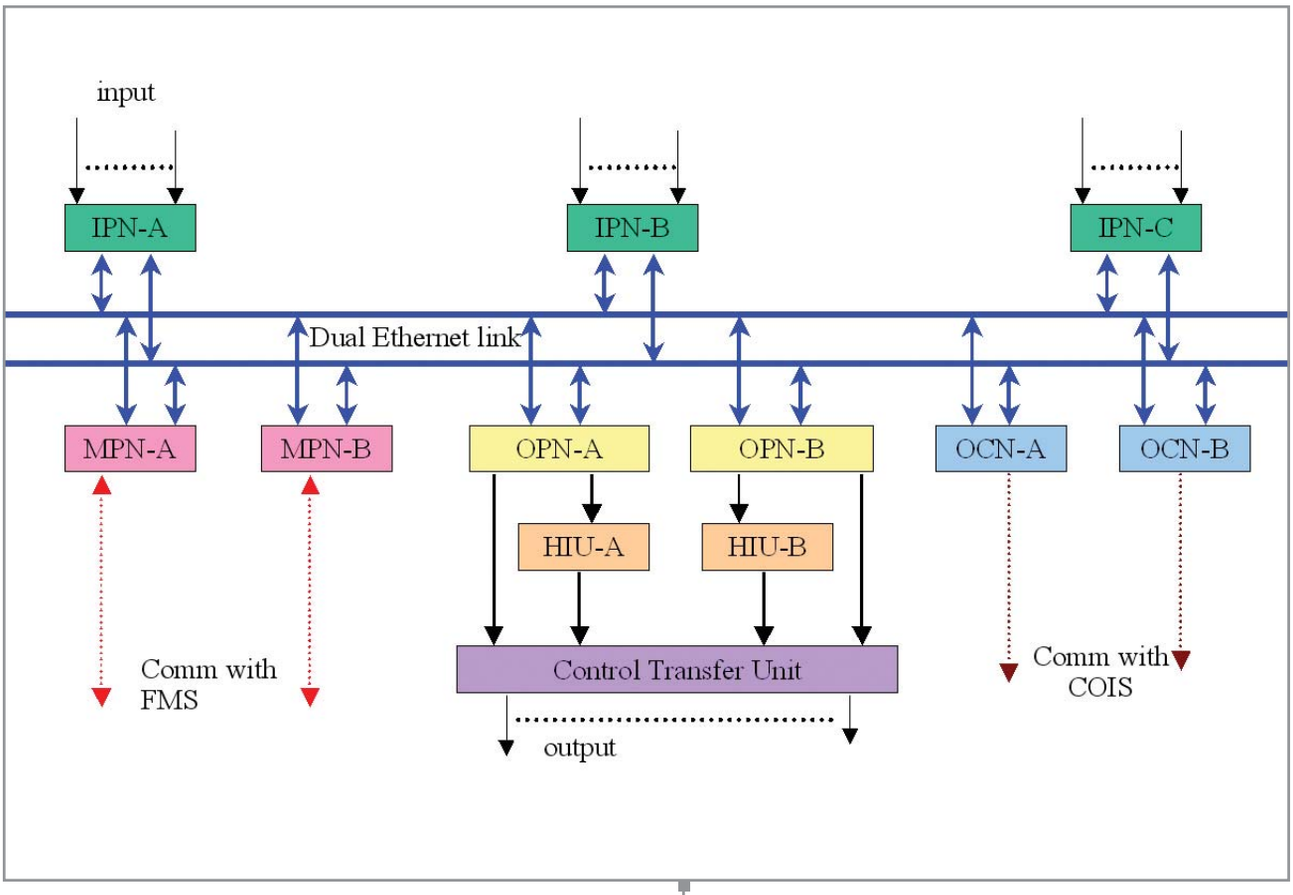
PDCS – Reactor Protection System 1 Architecture

Multinodal Reactor Regulating System (RRS) for TAPS 3 & 4

RRS is an important control system, to maintain reactor power at the desired level. The 540 MWe TAPS 3 & 4 PHWR cores are large; the power measurement devices and control devices are new and the control strategies are also new. Zonal control of neutron flux, shutoff rods withdrawal on startup, and step back are some of the new functions necessitating special considerations in development of RRS.

Reactor Regulating System for TAPS 3 & 4 is configured as a functionally partitioned distributed control system with nine nodes, linked by dual redundant high speed Ethernet. These nodes work independently and perform their

RRS Channel Rack



RRS Architecture

respective functions. The three instrumentation channel inputs are handled independently by three input nodes (IPNs) while control functions are provided by the redundant main processing nodes (MPNs) and the two output nodes (OPNs). Operator interaction is provided by two Operator consoles (OCNs), from where both power maneuvering and manual operation of reactivity devices are carried out. The outputs from the OPNs are routed through Hardware Interlock Units to limit the rate of addition of reactivity. Whenever any control signal becomes faulty, Control Transfer Unit transfers control to the healthy signal of the other OPN.

B.B. Biswas <bbbiswas@barc.gov.in>

■ Programmable Digital Comparator System for Process Control System (PDCS-PCS) for TAPS 3 & 4

PDCS-PCS is a computerized system that performs reactor setback, alarm annunciation and operation of pumps, valves, etc. PDCS is configured as triplicated Alarm Unit (AU) and redundant Display Unit (DU), thus isolating the alarm generation and information functions. AU does the signal scanning and alarm generation while DU provides operator interface. Main functions of AU are to scan 144 analog signals of various types from the field, validate the inputs, compare programmable setpoints and generate alarm output to be used for various process control purposes. DU provides operator interface to view various parameters in various formats like table, bar graph, and trends. It also allows operator to configure and re-configure system under privileged access.

Since PDCS is a safety-related system, defense-in-depth has been built into the system at every level. Fault-tolerance and fail-safeness is built-in by having exhaustive self-diagnosis and redundancy. The system, though in-existence in our NPPs from KAPS, it has been continuously evolving, from KAPS to Kaiga 1 & 2, RAPS 3 & 4 and now for TAPS 3 & 4.

B.B. Biswas <bbbiswas@barc.gov.in>

■ Dual Processor Hot Standby Process Control System (DPHS-PCS) for TAPS 3 & 4

Microcomputer-based Fault tolerant real time Process Control System (PCS) based on DPHS architecture has been designed and developed for 540 MWe PHWRs in TAPS 3 & 4. The system controls Primary Heat Transport (PHT) system pressure, Pressuriser pressure, Pressuriser level, Bleed condenser pressure, Bleed condenser level and Steam generator pressure. The control computers implementing the process regulation functions are networked over dual redundant fiber optic Ethernet network with a Personal Computer (PC)-based console and two PC-driven display units. The control computer software, networking software and Human Machine Interface (HMI) software for PC console and display computers for this safety related system were developed following systematic, carefully controlled, fully documented and reviewable software engineering process with concurrently performed Verification and Validation (V & V) activities by an independent team. The system has been installed and commissioned at TAPS 4 and is operating successfully at full power.

Dual Processor Hot Standby (DPHS) Configuration

The computer based systems for safety related applications in nuclear power plants have to meet stringent requirements like enhanced reliability, safety and security. Dual Processor Hot Standby (DPHS) architecture has been designed to meet these requirements. The Dual Processor Hot Standby architecture consists of two independent and identical computer systems, each receiving all the field inputs and operator commands. While one system is controlling the process, other system acts as hot standby. Each of these computer systems employs dual processors. The dual processor pair shares common Input/Output (I/O) boards for all digital and analog inputs and performs all the control and logic functions in an identical manner. The dual processors in each system compare the computed output signals through dual port RAM and generate diagnostic information based on any mismatches found. If the diagnostics programs and/or any of the two watchdog timers detect conditions indicating fault in the system, then the control output connections to control elements are automatically switched from the faulty system to the healthy standby system through the Control Transfer Unit (CTU). The comparison of their computed outputs by the dual processors of DPHS architecture ensures wide fault coverage and hot standby ensures high availability. The DPHS architecture was used in Process Control Systems and Reactor Regulating Systems of Kaiga-1&2 and RAPP-3&4. It has also been used in Process Control Systems of TAPP-3&4.

DPHS Process Control System (DPHS-PCS) for 540 MWe TAPS 4

C.K.Pithawa <pithawa@barc.gov.in>

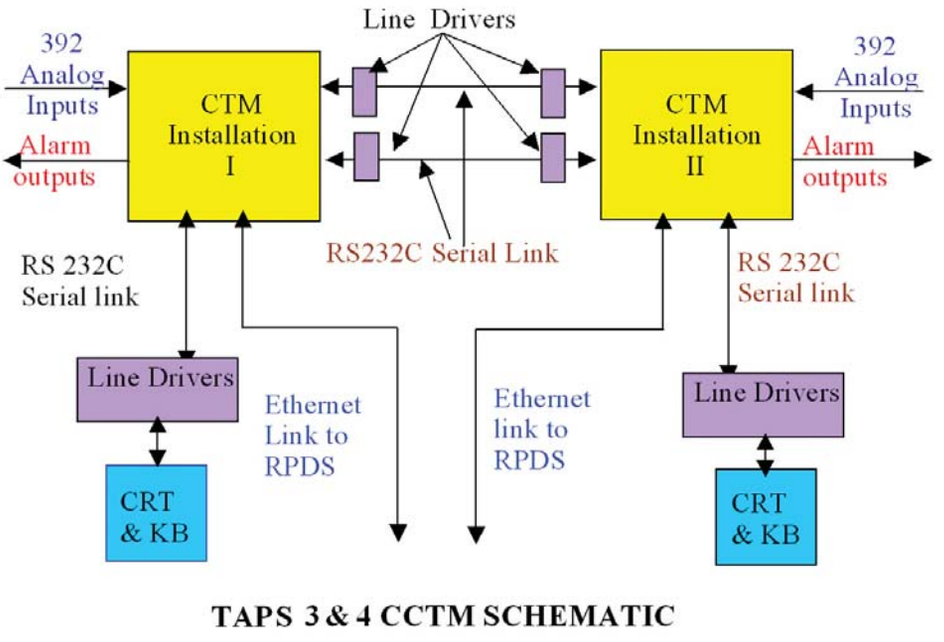
Computerized Channel Temperature Monitoring System for TAPS 3 & 4

Computerized Channel Temperature Monitoring System (CCTM) monitors the outlet temperature of all the coolant channels and thus indirectly detects low coolant flow in a channel. It also helps in efficient fuel management. There has been a continuous evolution in the functionality, hardware and software of this system since CCTM was first introduced in MAPS. With increased confidence in computer-based systems, the CCTM system has grown from a simple monitoring system to a safety related system, generating reactor setback.

TAPS 3 & 4 CCTM systems perform the main functions of monitoring the channel outlet temperatures, generation of alarms and generation of Setback. Two numbers of RTDs (Resistance Temperature Detectors) are mounted on each of 392-channel outlets for measuring the temperature and are connected to two identical and independent computerized systems. The RTD is excited by a 10 mA pulse eliminating RTD self-heating error and resulting in increased margin for reactor operation.

In line with the current trend for integration of plant wide data at a single location, CCTM system sends the data to Reactor Parameter Display System (RPDS) which acts as one of the gateways to COIS. Additionally, CCTM system provides minimal operator interface through local CRT, for use in case of failure of the RPDS or the link to the RPDS.This system implements some additional features not present in previous CCTM systems. These are :

- Checking of Irrational low limit
- Dynamic alarm generation
- Online setback test
- Switching of failed RTDs between installations
- Ethernet connectivity



TAPS 3 & 4 CCTM SCHEMATIC

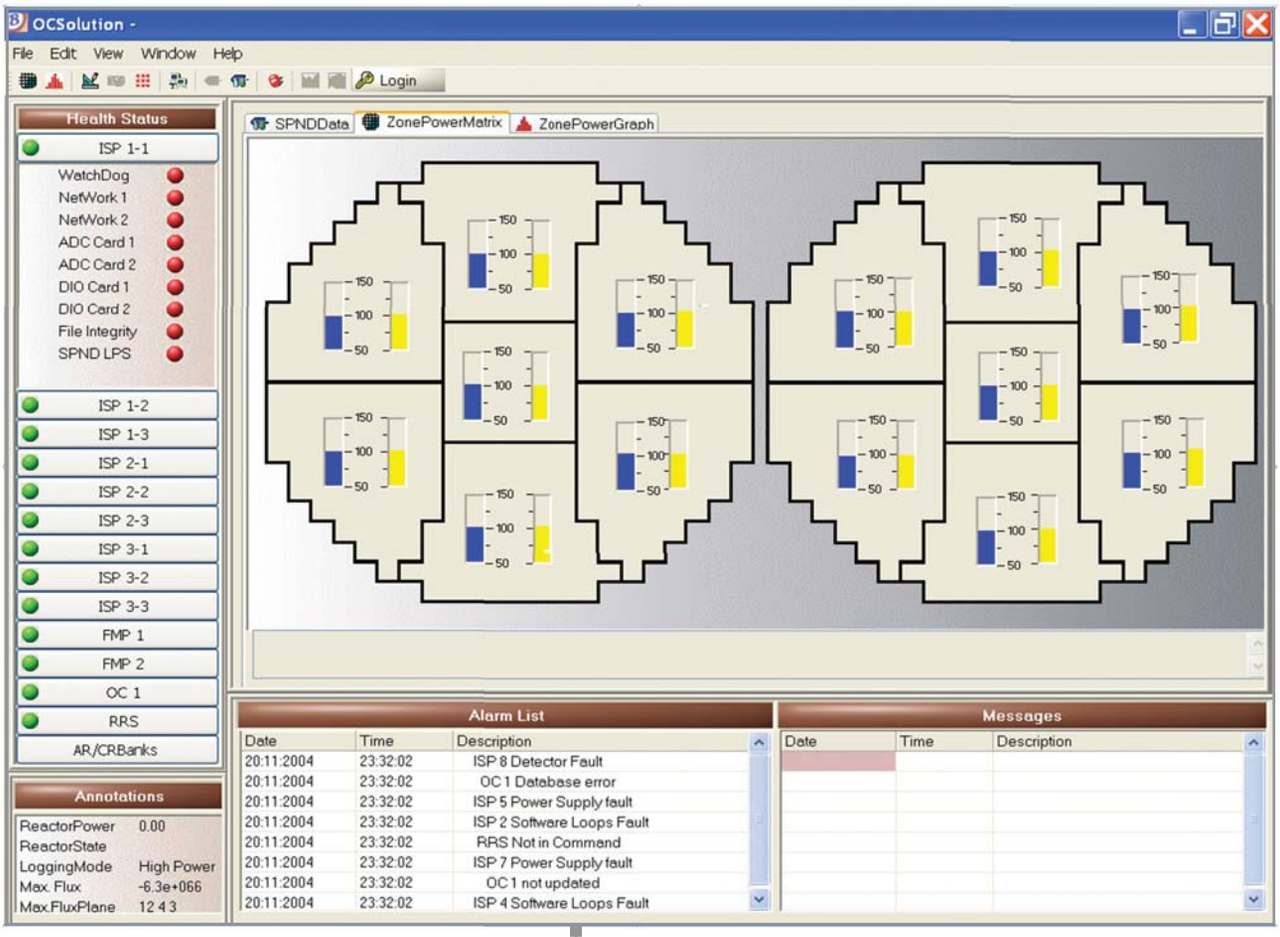
The CCTM system is built around a CPU board based on a 68020 microprocessor, with a math co-processor. The system configuration consists of RIM (RTD input module), ROM (Relay output module) and an independent Ethernet communications module, which handles the ethernet communication link with the RPDS. The graphical user interface (GUI) function is provided on the RPDS. IEC–880 and MISRA-C guidelines were followed for development of software. The developed code was checked for MISRA C compliance using CASE tools. The complexity of the developed code was also checked and was limited to the level specified in the Programming guidelines. System testing, verification and validation were carried out as per the laid down procedures. This ensured the quality of the software.

G. Ganesh <ganeshg@barc.gov.in>

■ Flux Mapping System for TAPS 3 & 4

Flux Mapping System has been developed for 540 MWe reactors TAPS 3 & 4 and installed at TAPS 4. The system periodically acquires neutron flux signals sensed by in-core Vanadium Self Powered Neutron Detectors (SPNDs) located at different positions in the reactor core. The system computes neutron flux profile and average thermal power in each of the fourteen zones and sends the zone power correction factors to Reactor Regulating System for computation of flux tilts. It also gives other related information like Burn-up, build-up history and provides interfaces to Computer-based Operator Information System (COIS).

System is designed as 3-tier distributed fault-tolerant system. The three tiers are: Nine Input Scanning Processor (ISP) sub-nodes, dual redundant Flux Mapping Processors (FMP) nodes, and dual redundant Operator console (OC) nodes – all inter connected by dual redundant Ethernet optical links. ISP nodes are located in the reactor building and receive neutron flux signals from in-house developed SPND amplifiers and send the scanned data to the FMP nodes located in the control equipment room. This arrangement resulted in substantial reduction in cabling from reactor building to the equipment room. Each of ISP and FMP nodes is an industrial grade PC with embedded XP operating system on disk-on-chip for rugged construction. OC nodes are normal PC running XP professional.



GUI at Operator Console

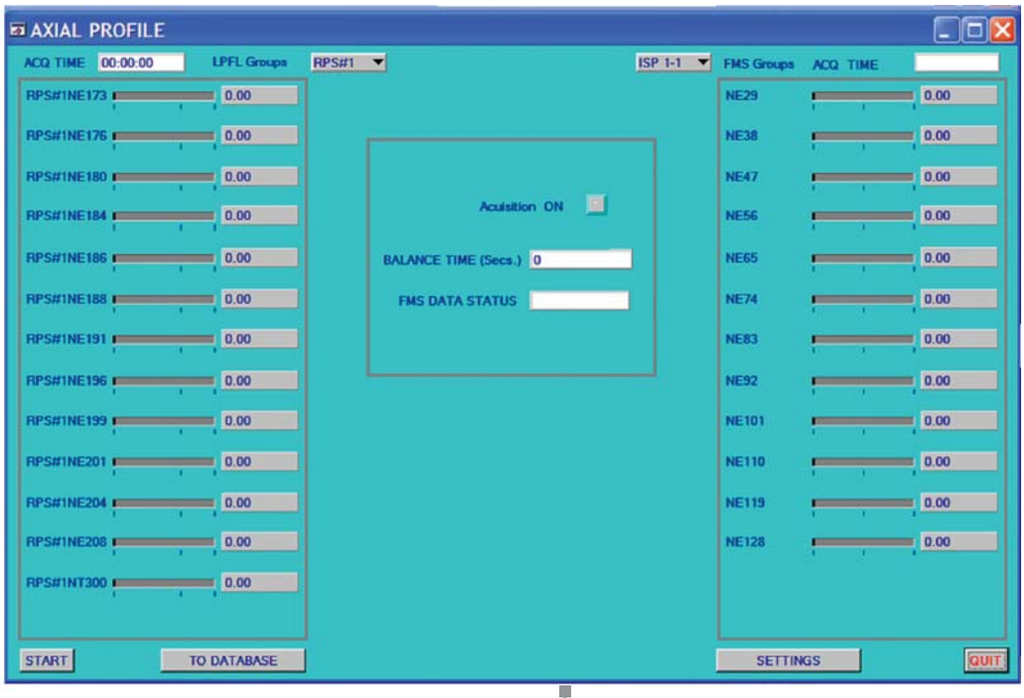
Flux Mapping Processors (FMP) nodes perform the core functions of FMS i.e. periodically collect neutron flux data from ISP nodes, compute flux profile and zone power correction factors and send these to RRS and OC nodes. OC nodes provide operator interface and periodically send neutron flux data, zone-power correction factors and other data to COIS.

Object-oriented paradigm and agile software engineering practices were followed over the entire software development life cycle to meet system quality requirements. Practices followed include: Iterative incremental development model, test-driven development, continuous integration and refractoring. Software Architecture and design is based on Software Patterns. Rational Case tool suite was used for requirements preparation and analysis, modeling, design, testing, performance analysis, code coverage, and leak detection.

D. Das <ddas@barc.gov.in>
M.P.Diwakar <netsoft@barc.gov.in>

■ Low Power Flux Logging (LPFL) System for TAPS 4

This system is designed for use in PHASE-B experiments by Reactor Physicists. This system logs signals from SPNDs and Ion Chambers located in HFU and VFU of TAPS 4 reactor. Signals from Cobalt SPNDs are logged via hardware consisting of PC plug-in card and data from 102 Vanadium SPNDs are logged from the Flux Mapping Systems' ISP via FMS network. Position information of control rods, shutoff rods and various trip events are also logged.This data, along with parameter setting information is



Axial Profile Screen of LPFL System

transferred to database for offline studies. Logged signals are available in database for ease of viewing the data in required report format.

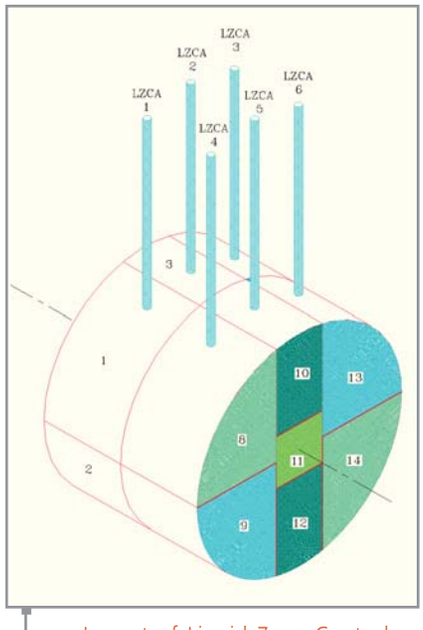
D. Das <ddas@barc.gov.in>
T.S. Ananthakrishnan <anant@barc.gov.in>

■ Liquid Zone Control System (LZCS) for TAPS 3 & 4

Among the different control mechanisms in the 540 MWe PHWR, the LZCS is the most important for fine control of reactor power and power distribution. It refers to the system consisting of six Liquid Zone Control Assemblies containing fourteen Zone Control Compartments (ZCCs), associated equipment for circulation of liquid absorber and inert cover gas in the ZCCs, and measuring and control devices. In the 540 MWe PHWR, it fulfills the following purposes:

(a) Fine reactivity control on a continuous basis for control of global reactor power and spatial flux distribution,
(b) Compensate for minor reactivity perturbations resulting due to perturbations in fuel, moderator, and coolant temperatures and also due to refueling, and
(c) Suppress the Xenon induced power oscillations.

These purposes are fulfilled by reactivity control through variation of liquid absorber levels in ZCCs. Demineralized light water is used as absorber while helium is used as the inert cover gas.



Layout of Liquid Zone Control Assemblies in 540 MWe PHWR

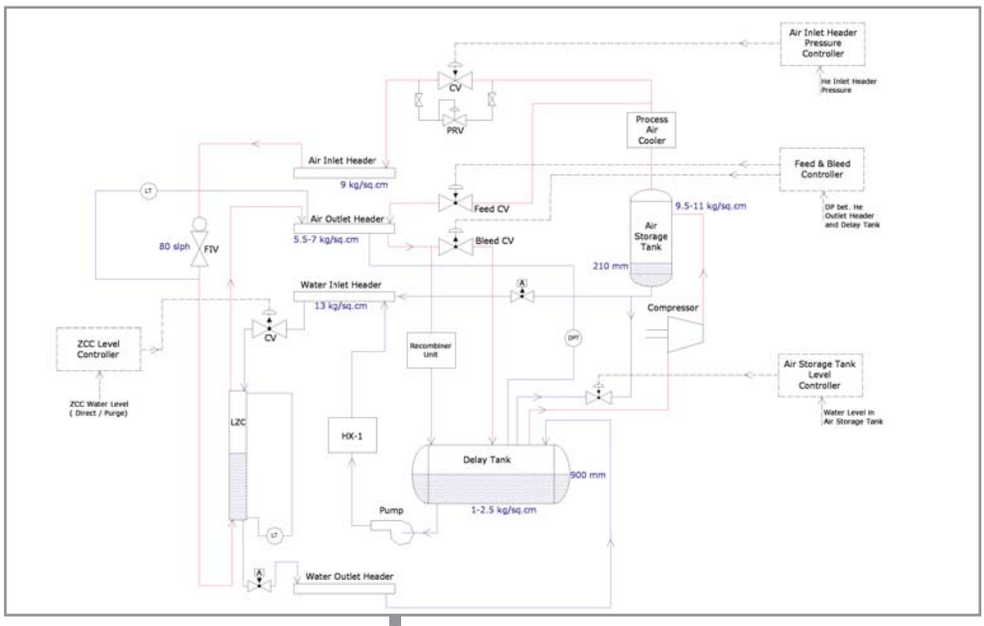
As shown in the simplified flowsheet, water is pumped from the delay tank into the water inlet header through a heat exchanger. There are 14 control valves called LZC control valves in the water inlet lines of the 14 ZCCs. Depending on the signal to these valves, water inflow to ZCCs can be individually varied. A constant outflow of water takes place from the ZCCs through respective water outflow lines and is collected in the delay tank through a common water outlet header.

For maintaining the water outflow rate at a constant value, the differential pressure between the ZCCs and the delay tank should be maintained constant. This is achieved by connecting all the ZCCs to a common gas outlet header through the respective gas outlet tubes in which gas flow can take place in either direction depending on the pressure difference between the ZCC and the gas outlet header. The differential pressure between the gas outlet header and the delay tank is sensed by a differential pressure sensing instrument. A feed-bleed control system is operated depending upon this signal. The water level in each ZCC is measured as well as gas is maintained under continuous circulation by a bubbler arrangement. Constant gas flow is maintained by a purge flow regulator through the gas inlet tube connected between the gas inlet header and the ZCCs.

A compressor takes suction from the delay tank, compresses the process gas and accumulates it at high pressure in the gas storage tank. Depending upon the position of the feed control valves variable gas flow takes place into the gas outlet header. A PRV connected between the gas storage tank and the gas inlet header maintains the header pressure at a constant value.

The LZC control valves are maneuvered by the RRS, based on deviation of the global power from demand, deviation of zonal power levels from average zonal power and/or deviation of ZCC water levels from average water level in ZCCs.

LZCS being used for the first time in our reactors, it was considered necessary to understand the behaviour of the system before its installation in TAPS 3 & 4. Hence a test set of LZCS was installed at Reactor Control Division (RCnD), with the objectives of design validation (Establishing commissioning procedure, Tuning and optimisation of controllers, Collection of useful data during normal and abnormal operational transients) and integrated testing with RRS algorithms. The arrangement of LZCAs and equipment, piping layout and operational conditions for the test setup are identical to those in the case of 540 MWe PHWR so that the hydraulic characteristics of the LZCS test setup are fair representatives of those in the LZC System. Provision was also made to interconnect the LZCS test setup with a core and RRS simulator for testing of integrated behaviour of the LZCS with RRS algorithms.



Simplified Flowsheet of LZCS Test Setup

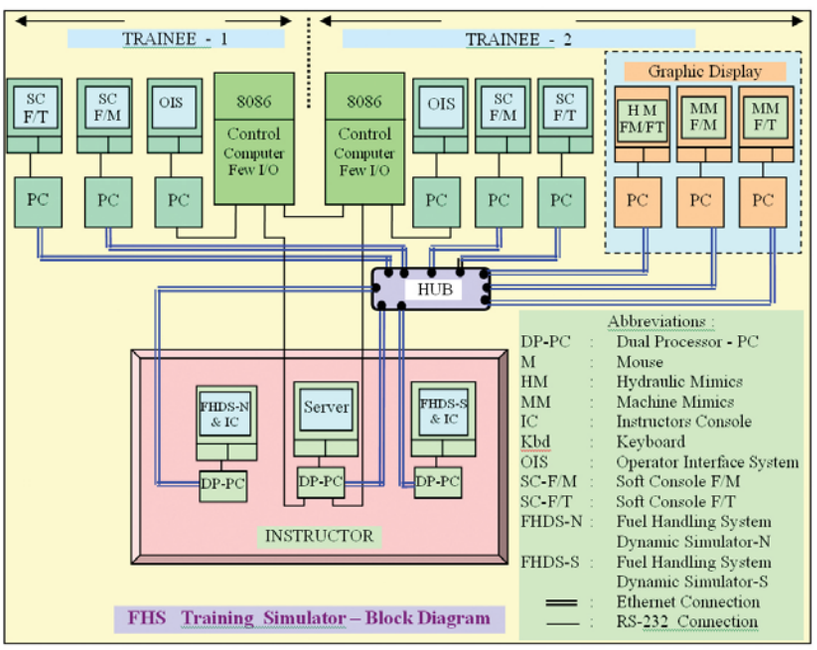
The test setup was commissioned in December 2002 and major part of experiments was conducted before installation of LZCS began in TAPS 4. With the experience that was gained on the LZCS test setup, installation and commissioning of LZCS at TAPS 4 was very smoothly carried out and some problems that surfaced were easily understood and resolved. Detailed study on the LZC System alongwith the core and RRS simulator outside the reactor environment has paid far beyond its cost by way of savings in expenditure through reduction of overall commissioning time at Tarapur site.

A.P.Tiwari <aptiwari@barc.gov.in>

Fuel Handling Control Systems for PHWRs

On-power refueling is an essential requirement for NPPs based on PHWRs. Two fuelling machines work in synchronism, one at each end of the selected reactor channel for carrying out the regular on power refueling. The fuelling machines receive new fuel and discharge spent fuel through fuel transfer system. The fuel handling control systems for all NPPs from Narora onwards have been computerized using the designs developed at BARC. The earlier control systems for two units at Narora and for two units at Kakrapar NPPs were configured around imported computers as one master and two slaves, the computers being different for the two sites. Subsequent control systems for two units at Kaiga and for two units at Rajasthan NPPs are configured around indigenous microcomputers. These control systems utilize two 8086 microcomputers, one for each side of PHWR. The design was perfected to achieve full auto-mode operation. This new control system design was subsequently made compatible and commissioned at Narora reactor site for Unit-1 in July 2002 and for Unit-2 in April 2005.

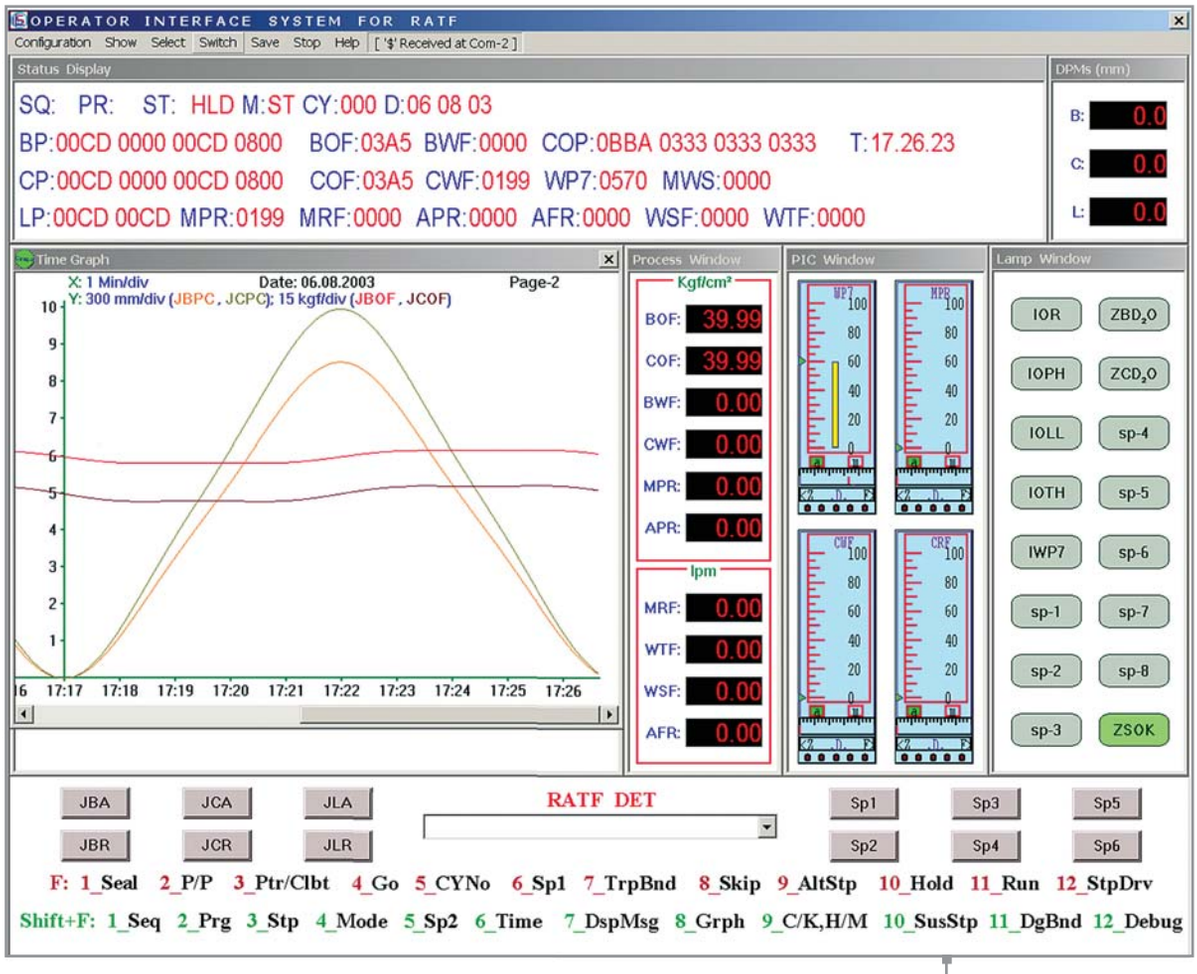
Since the computerized control systems for on power refueling were in operation at eight NPPs, it was felt desirable to develop a simulator for operator training. The Fuel Handling System (FHS) training simulator has been configured around a network of eleven PCs and two 8086 microcomputers. Screen based control consoles of fuelling machine and fuel transfer system, dynamic simulator of field devices, instructors console and network software in client-server configuration have been provided. Instructor could create various training sessions and train the operator for correct operating practices and to handle malfunction situations associated with inconsistencies & malfunctions in field actuators and sensors. The on-power refueling operation in NPPs is highly operation intensive whenever full auto mode of operation is required. This is because of sluggishness of field devices and the need to satisfy all interlocks. The training simulator system was handed over by BARC to Nuclear Training Center (NTC), Kaiga, in April 2002.



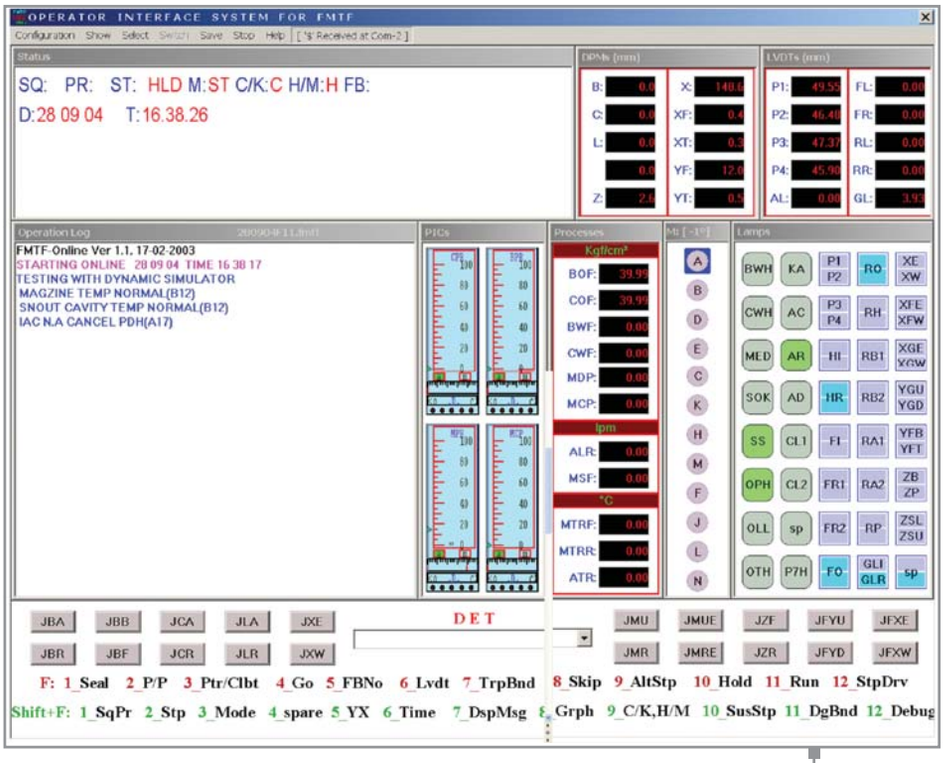
For the two 540 MWe PHWR based NPPs at Tarapur, the control system development work involved utilization of state-of-the-art computer hardware and software technologies. There are many innovative features in the design of mechanical assemblies of fuelling machine. Ram assembly is a very critical component of FM head. For testing and validation of mechanical design of the first ram assembly, Ram Assembly Test Facility (RATF) has been setup. To enable testing and validation of various mechanical design concepts of first FM head, Fuelling Machine Test Facility (FMTF) has been setup. RATF & FMTF control systems have been commissioned at BARC.

These control systems have been configured using the latest hardware and the control requirements implemented through software, taking advantage of the current technologies. The hardware has been reduced to minimum, so as to achieve high reliability and low maintenance, since the software performance is unaffected by ageing. As the failures in software are due to design deficiencies, considerable efforts have been made for thorough testing of control system using real time dynamic simulators as replacements for passive simulator hardware used earlier. These dynamic simulators are PC-based, having software models of fuelling machine components and are developed specifically for the purpose.

The control systems have PC-based Operator Interface System (OIS) replacing the large operators console, which were the characteristic feature of fuelling machine operations.

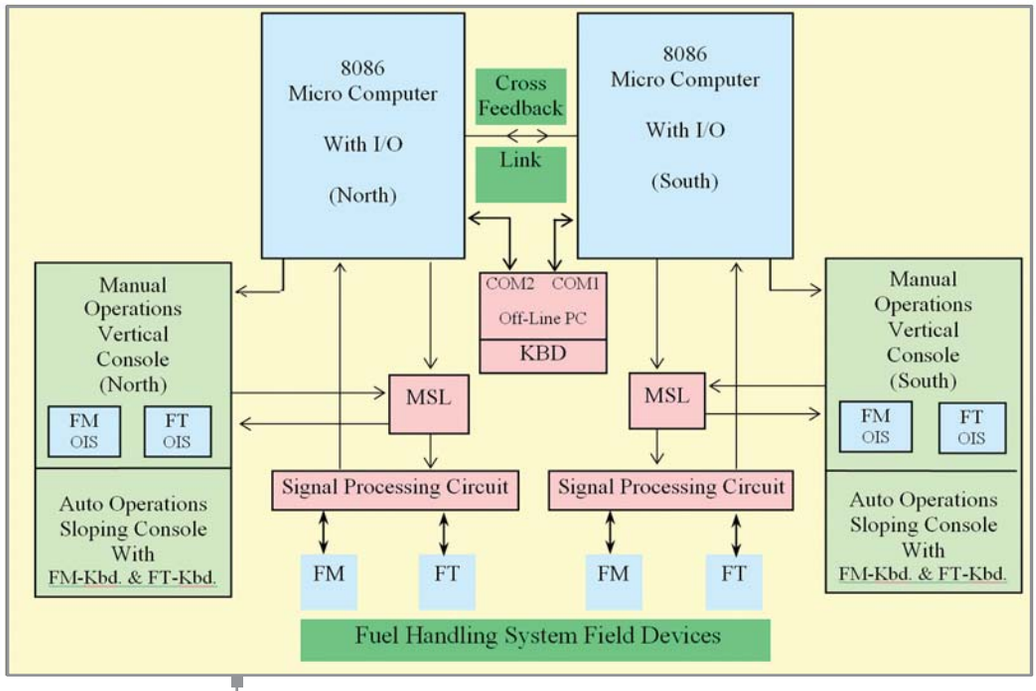


Operator Interface for RATF Control System



Fuel Handling Control System Operator Interface
for FM & FT (TAPS 4)

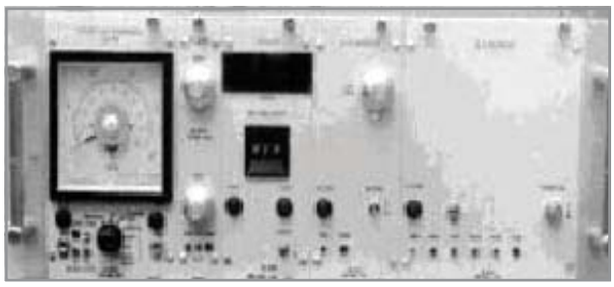
RATF control system was commissioned in January 2003 and FMTF control system in September 2004. The screen based OIS of FMTF is much complex as it handles the complete fuelling machine than the OIS of RATF. The work consists of providing Digital Panel Meters (DPMs), Indicating Alarm Meters (IAMs), PID controllers, lamps, meters and operate buttons through software. Display of status through texts and plotting of analog signal is provided.

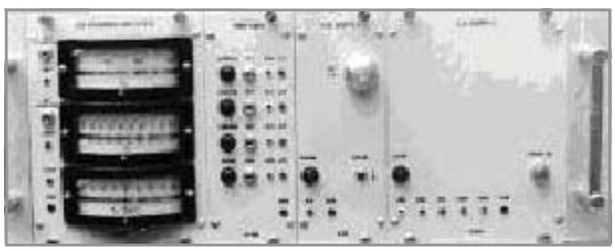


Fuel Handling Control System Block Diagram (TAPS 3 & 4)

For Fuel Handling Control System of Tarapur (TAPS 3 & 4), the control system software is designed, developed and commissioned at reactor site by BARC engineers whereas the control system hardware was fabricated, installed and commissioned at site by M/s ECIL. The operator interface system design has made use of the experience gained from control systems developed earlier for test facilities. In addition, it provides on-line mimics of the operation of field systems. This is with a view to provide full operability of the complex fuel handling system using keyboard and screen as operator interface. As the operator would be focused on a much smaller area during operation of on-power refuelling, it is expected to cause less operator fatigue.

Vinay Kumar <vinayk@barc.gov.in>





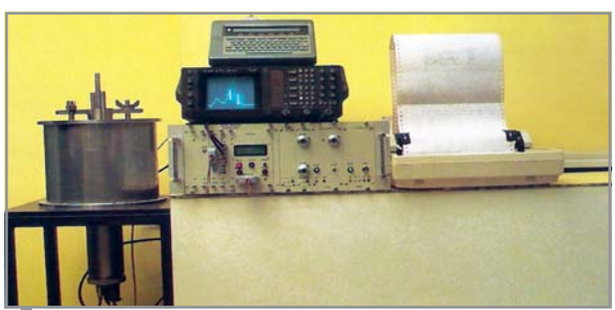
Neutronic Instrumentation

The design, development and deployment of the instrumentation including detectors required for monitoring the reactor core status i.e. neutron flux in all states of the reactor i.e. start-up, shutdown and operation has been met with by in-house developmental efforts for all the indigenous reactors in the country. The activity started with the design of reactor instrumentation for ASPARA reactor in late 1950s and BARC has been developing the reactor instrumentation for Zerlina, Purnima, Dhruva, Kamini and all the indigenous power reactors in the country. Many of the reactor instrumentation systems earlier installed for the reactors have been upgraded to improve the performance and enhance the operation life by indigenous design techniques.

There have been continuing efforts in evolving new designs by incorporating new design techniques and in-house development of high performance components to achieve better accuracy and long time performance.

Neutronic and Radioactivity Release Monitoring Channels

The systems include ruggedised charge/current preamplifiers, processing channels for pulse range, intermediate (Campbell/DC) range and power (Linear DC) range incorporating various types of neutron detectors including self-powered neutron detectors. The critical systems to monitor on-line radioactivity releases from the plants have been indigenously developed and deployed.



Iodine Monitor

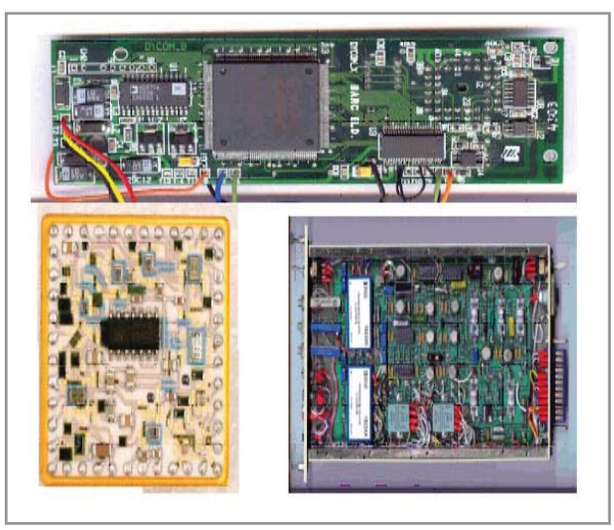
Air Particulate Monitor

Argon Monitor

The know-how for all the reactor instrumentation channels i.e. start-up, intermediate and power range used in power plants were transferred to ECIL, Hyderabad and similar requirements of new power plants are met with using these designs developed by ECIL.

SPND Amplifier

The in-house developed SPND amplifier has the on-line Insulation resistance measurements feature and operates in low and high power ranges covering total six decades of signal range. A Hybrid Micro Circuit (HMC) has been developed for this.



An on-line DSP-based algorithm is developed to speed up the response of Vanadium SPND from 5 minutes to 40 milli-seconds. The algorithm was subsequently coded to an FPGA and incorporated on a piggyback PCB is fitted inside the existing SPND amplifier. The algorithm is under long-term validation at TAPS 4. A patent application is filed for DyCom algorithm and is presently under process.

Development of Self-Powered Neutron Detector (SPND) Amplifier Hybrid Micro-Circuit (HMC), Amitabha Das, Debashis Das and S. K. Kataria, **Symposium on Compact Nuclear Instrumentation and Radiation Detectors-2005,** March 2-4,2005, Defence Lab, Jodhpur

Field Programmable gate array (FPGA) implementation of Dynamic Compensation (DyCom) algorithm for Vanadium self powered neutron detectors, A.Das, M. Y. Dixit, D. Das, S. P. Chaganty and S. K. Kataria, in **National Symposium on Nuclear Instrumentation (NSNI),** Feb.17-20 2004

MCA-Based Iodine and Argon Monitors

A PC-based Multichannel Analyzer to monitor the release of Iodine and Argon through the stack of Dhruva reactor has been developed and has been put under long-term observation. This system is capable of detecting small release of Iodine in high background of Argon.

D. Das <ddas@barc.gov.in>

RAdiation Data Acquisition System (RADAS)

RAdiation Monitoring Data Acquisition System (RADAS) is a Dual, rugged, Industrial-PC-based fault-tolerant data acquisition system that monitors radioactivity in and around nuclear installations. It can handle up to 96 analog and 22 digital inputs. The inputs are received from standardized Radiation Sensors which are DC-powered by RADAS. The system scans all the inputs and generates alarm report using channel configuration. Features like self test and password protection for access control are built in.

The RADAS

R. K. Jakati <rkjakati@barc.gov.in>
M. P. Diwakar <netsoft@barc.gov.in>

the advanced features of the AHWR reactor. The control & monitoring of AHWR systems are to be carried out through fully computer-based operator interfaces (soft HMI), except for safety systems, for which control and monitoring is performed from dedicated hardwired panels.

There are two operator workstations and a shift supervisor console and all of them are fully computerized. The control and monitoring of the plant is performed from these fully computerized operator workstations.

A state-of-the-art C&I architecture based on extensive use of pre-qualified programmable controllers and networking has been conceived for this plant. Use of pre-configured controllers enables uniformity in hardware, software, interface etc. and eases the integration into the larger C&I system. It also eases commissioning and servicing.

Jose Joseph <jjoseph@barc.gov.in>

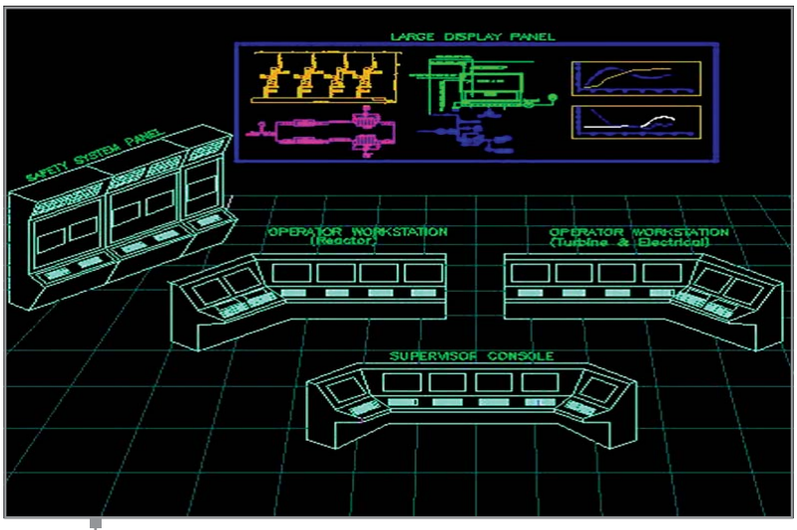
1.2 RESEARCH & DEVELOPMENT PROGRAM FOR DEVELOPMENT OF C&I FOR AHWR, PFBR AND RESEARCH REACTORS

■ Advanced C & I and Control Room for AHWR

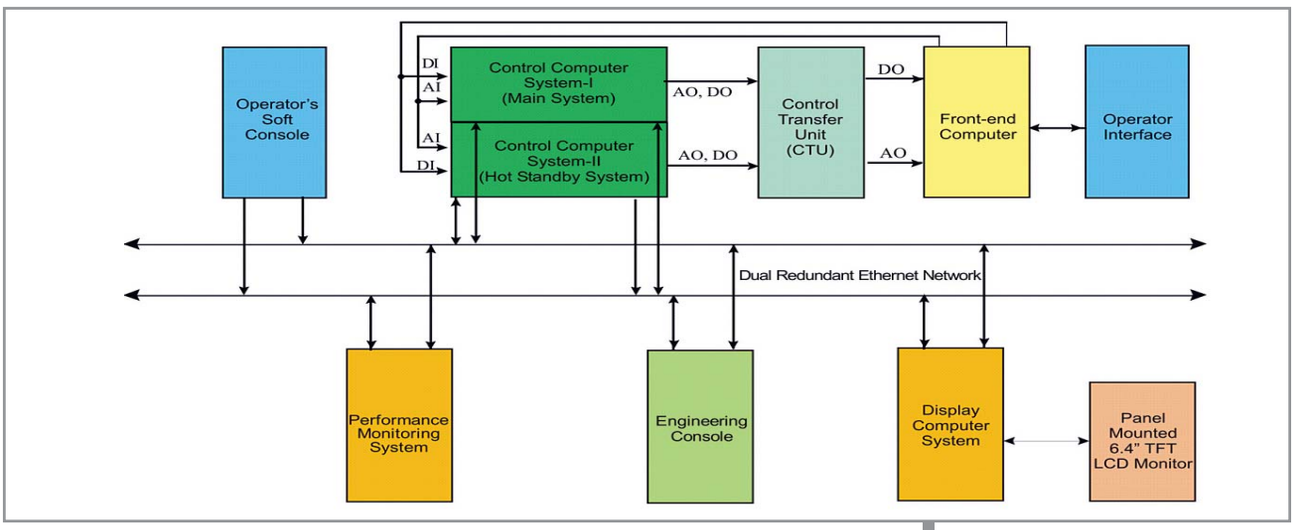
State-of-the-art C & I and a modern control room are being designed for operation and monitoring of the plant in tune with

■ User Configurable Advanced Control System (UCACS)

A User Configurable Advanced Control System (UCACS) development facility is being built by the Reactor Control Division. This will be used to design and develop safety-related process control applications for use in AHWR and future nuclear power



Main Control Room for AHWR



User Configurable Advanced Control System-Block Diagram

plants and research reactors. UCACS will facilitate high-level user configurability in building process control applications while meeting enhanced reliability and regulatory requirements. UCACS has a multi-nodal architecture wherein all the nodes are connected on dual redundant fiber optic network. UCACS has configurable operator's soft console to simulate operator panel and configurable front-end computer to simulate field inputs/outputs related to the process. The performance monitoring station will provide human machine interface for the controlled processes and also support functionalities for fine-tuning the control system. To meet high availability requirements, UCACS uses fault tolerant configuration and software is being developed under a software quality assurance plan to meet applicable regulatory standards. The prototype UCACS control computer is already commissioned. The software development for different components of UCACS is at an advanced stage.

C.K.Pithawa <pithawa@barc.gov.in>

■ Advanced Operator Information System (AOIS) for AHWR

Availability of intelligent field devices and advances in networking technology have introduced a new paradigm in plant automation. The automation system can now be split into several layers according to the requirement of the plant.

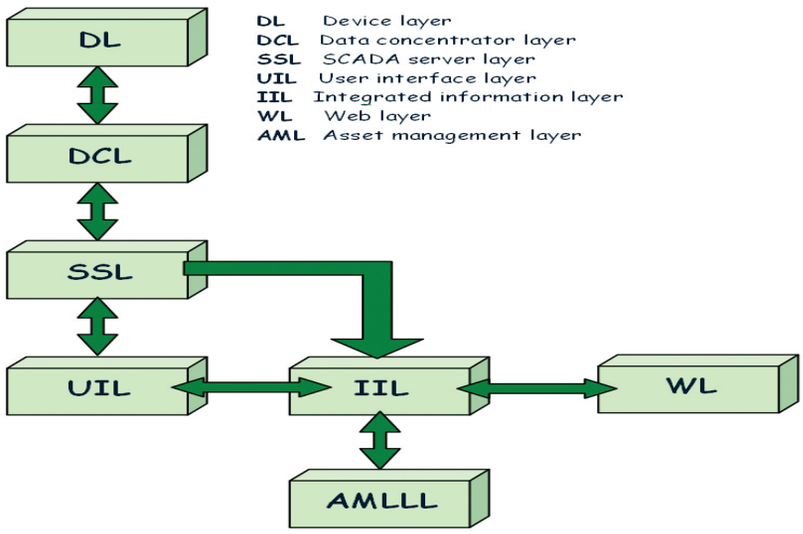
- ***Device layer***
- ***Data concentrator layer***
- ***SCADA server layer***
- ***User interface layer***
- ***Integrated information layer***
- ***Web layer***
- ***Asset management layer***

Today, when intelligent field devices are used, communication is possible from the Web layer/Asset management layer down to the last transmitter or actuator.

Major advantages of the above architecture are as follows:

- ***Flexibility in development***
- ***Use of standard and open technologies***
- ***Low coupling among layers***
- ***Easy to customize***
- ***Robust architecture***
- ***Improved data security***
- ***Easy maintainability***
- ***Easy integration of in-house developed components with third party components.***

The instrumentation and control systems of the Advanced Heavy Water Reactor (AHWR) will acquire a large amount of plant parameters using computer-based front-end systems. AOIS will



acquire complete plant information in real-time from these systems and present it to operators throughout the plant in a composite manner. This real-time data presentation is the key to more efficient use of resources and personnel, and ultimately, to more efficiency. The seven-layered architecture of AOIS has been designed and is under implementation.

Open standards and technology have been used for the development of automation components at various layers and for communication between them.

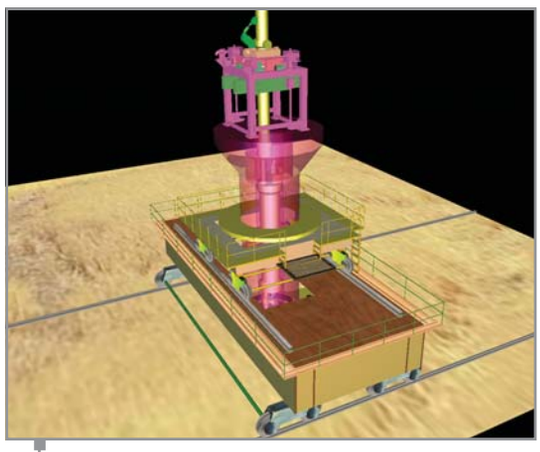
AOIS collects data from safety, non-safety and safety-related systems. Segregation of systems is done at the DCL and SSL to improve the overall reliability of system. However, data from all three types of systems is integrated at IIL to provide unified view of the power plant data.

Device layer consists of microprocessor-based systems performing data acquisition and control. Ethernet is used to connect Device layer to DCL. Multitude of standard protocols are used for data exchange. DCL and SSL are deployed on server computers. Communication between DCL and SSL is achieved using OPC servers. UIL is deployed on general purpose computers. Web layer comprises of in-house developed web-server applications along with standard Web Server and is deployed on a gateway computer. IIL is deployed on a high performance computer with redundant storage. In-house developed software is being tested according to applicable standards.

G. Ganesh <**ganeshg@barc.gov.in**>

Control System for AHWR Refuelling

The systems of AHWR and the fuelling machine are among the first of their kind and therefore detailed understanding and demonstration is necessary. PC-based software mimics are being developed to display the operation of AHWR fuelling machine and its various components. On the mimics' screen, one active window and twelve passive windows are provided. Different modules and systems of fuelling machine reside in these passive windows, from where it can be selectively brought to active window through the use of mouse button. Module in the active



3D Mimic of AHWR Fuelling Machine

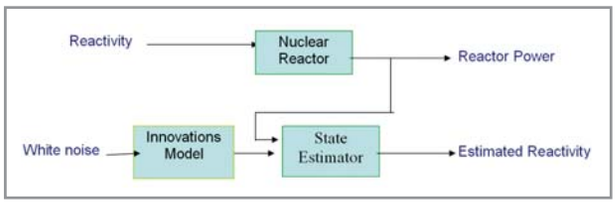
window can be enlarged to full screen and even otherwise the size of active window has been kept as four times the size of the passive window. Using the keyboard commands, the mimic operations are carried out in off-line mode. During on-line mode of operation, the mimic commands are received through the network; line in the control system demonstration setup and the keyboard & mouse is disabled. Typical module are: solid model of FM assembly, wire frame model of FM assembly, carriage assembly, carriage & trolley assembly, magazine assembly, FM support & ram assembly, separator assembly and snout assembly. Typical mimic operations through the keyboard consist of: zoom in or zoom out, X-Y-Z movements, rotation and various special operations.

Vinay Kumar <vinayk@barc.gov.in>

Reactivity Measurement based on Kalman Filtering Technique

An entirely new method, based on the Kalman Filtering Technique, was evolved and deployed for measurement of reactivity in nuclear reactors. The method based on Kalman filtering is capable of performing estimation in noisy environment.

The reactor power is computed assuming a reactivity variation and compared with the actual reactor power sensed by an ion chamber. The deviation between the computed and actual power is fed back to obtain corrected value of reactivity. Iterations are performed till the deviation between the actual power and computed value of power is the minimum in the least-squares sense.



The technique has been validated by conducting experiments at Apsara and Dhruva reactors. It has been established that reactivity measurement based on the Kalman filtering is superior to conventional methods based on period measurement or inverse point-kinetics.

With some additional algorithms, the reactivity meter is being configured for rod drop time measurement in PFBR, where it is not possible to install conventional sensors due to environmental and layout restrictions.

A.P.Tiwari <aptiwari@barc.gov.in>

PFBR Instrumentation

A wide range neutron core flux measurement and monitoring system using a single neutron detector is under development. The high temperature fission chamber operating in pulse, intermediate and power ranges has been used. The intermediate stage employs campbelling technique for better gamma discrimination, which is of the order of 10^6 R/hr. The higher frequency band of the detector is used to generate the Campbell signal to improve the response with acceptable fluctuation in this range. The preamplifier uses an in-house developed ultra low noise current circuit hybrid with an in-house developed ASIC.

The instrumentation also employs low power preamplifier with built-in detector supply for twenty-four delayed neutron detectors to reduce cable penetrations in the reactor building.The reactivity calculations are implemented in FPGA based on the solution of point kinetic equation to improve the response and calibration/test facilities.

The development to provide on-line remote testing of the neutronic channels by incorporating fault-tolerant connectivity to the plant safety bus using robust protocol is underway.

D. Das <ddas@barc.gov.in>

Inclined Fuel Transfer Machine (IFTM) Control System for PFBR

The control system for operating Inclined Fuel Transfer Machine (IFTM) of Prototype Fast Breeder Reactor (PFBR) at Kalpakkam is being developed. For demonstrating and finalizing the control logic and operator interface design in the absence of the target hardware (development of which is going on in parallel), a system consisting of network of three PCs has been configured. PCs implement dynamic simulator, operator interface and machine

mimics respectively. The dynamic simulator PC models the real time features of IFTM mechanisms. The operator interface PC also implements the control system software. The on-line mimics have been developed and used to demonstrate the actual operation as in field. Following this approach, it has become feasible to de-link the major part of the control system software development from finalisation & integration of the control system microcomputer hardware. The microcomputer hardware based on Motorola 68000-processor is presently being designed at IGCAR for various C&I systems of PFBR. The demonstration system can be used to train operators for execution of refueling sequences in auto mode and computer manual mode of operations.

Vinay Kumar <vinayk@barc.gov.in>

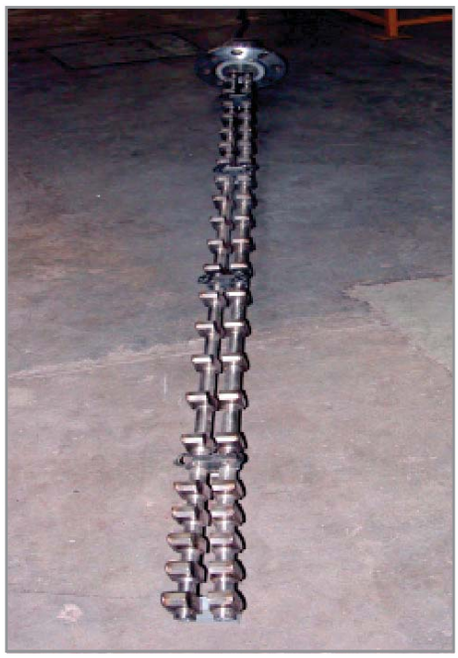
■ Sensors for High Temperature/High Pressure Applications

High Pressure, high Temperature Ultrasonic Level Sensors and Capacitive type Level Sensor have been developed for specific applications. Commercially available standard level sensors can not meet the requirement for the application. Hence, the following sensors have been developed by Reactor Control Division.

- ***Multi-point Ultrasonic Level Sensor***
- ***Single-point Ultrasonic Level Sensor***
- ***Flexible Capacitive type Level Sensor***

Multi-point Ultrasonic Level Sensor

The working principle of the level sensor is based on change in ultrasonic energy while passing through the liquid or gas due to difference in acoustic impedance of the medium. The level sensor consists of identical 23 pairs of ultrasonic transmitter receivers, which are placed at specific distance along the axis of sensor, covering the measurement range of 0 – 2500 mm. Ultrasonic transmitters are located opposite to ultrasonic receivers separated by a gap. The transmitting and receiving piezoelectric crystals are mounted in hermetically sealed stainless steel housings. The level sensor is interfaced with measuring electronics unit, which can be mounted remotely up to 20 m. When process medium



crosses the pair of transmitter receiver, measuring electronics unit generates discrete output for the corresponding pair and indicates level information. The output is also used for actuation of alarms when level is above or below the specified level. Level indication and alarm actuations are not affected by the change in fluid parameters due to change in process temperature and pressure. The sensor is designed for process pressures up to 200 kg/cm^2 and temperatures up to 250^{0}C.

Single-point Ultrasonic Level Sensor

The Single-point Ultrasonic Level Switch has been developed for

detecting high / low liquid level in process tanks with pressures up to 200 kg/cm^2 and temperature up to 250^{0}C. It can be used for detecting the presence of gas/air in equipment, present due to improper venting. The level sensor works on the same principle as the multi-point ultrasonic level sensor. The level switch is interfaced with measuring electronics unit, which can be mounted remotely up to 20 m.

Flexible Capacitance Level Probe

Flexible Capacitance type Level sensor has been developed for measurement of water level for measurement range of 0 – 2000 mm at process pressure of 70 kg/cm^2 and temperature up to 200^{0}C. The level probe has been designed for minimum bending radius of 600 mm and can be used where head room for installation is limited. The working principle of the level sensor is based on the difference in dielectric constants of liquid and gas. Hence, with the change in liquid level, the capacitance of the level probe changes linearly. The level sensor is interfaced with measuring electronics unit, which can be mounted remotely up to 30 m.

P.R.Patil <prpatil@barc.gov.in>

■ Electronic Hardware Standardization and Upgradation

A program has been developed for standardized hardware modules for use in future reactor and other applications. These boards are to be designed based on present day technology and components. Thrust was given to use FPGA/ASICs so as to improve the reliability of system by reducing component count. This also helps guard against obsolescence and constraints associated with import of electronic components.

Boards that are currently under various stages of development are Digital Input Board, Digital Output Board, Analog Input Board, Analog Output Board, 32 bit high performance CPU board on VME bus, Dual Ethernet Communication board on VME bus, Protocol converter between VME & I/O bus, I/O bus backplane, Data Acquisition Board and Remote I/O Board.

Input-Output (I/O) boards have been designed with on-board intelligence implemented in FPGA. The components used on these boards are low voltage devices (3.3, 2.5V etc) and SMD package leading to higher density and low power consumption. The boards have extensive diagnostics and self test features built into it.

Digital Input Board

The Digital Input Board is available on VME and IO bus. This board caters to 32 inputs and provides on-board isolation. Debouncing is applied to each input of the board and Debounce time is programmable. This board has got On-board self testing (FIT). The Bus interface is implemented in CPLD and the Sequencer is implemented in FPGA.

Digital Output Board

The Digital Output Board is available on VME and IO bus and generates 32 optically isolated outputs. This board has On-board Finite Impulse Testing. On failure of the system, the outputs are put into fail-safe state, which is programmable. The controller has been implemented in FPGA.

Analog Input Board

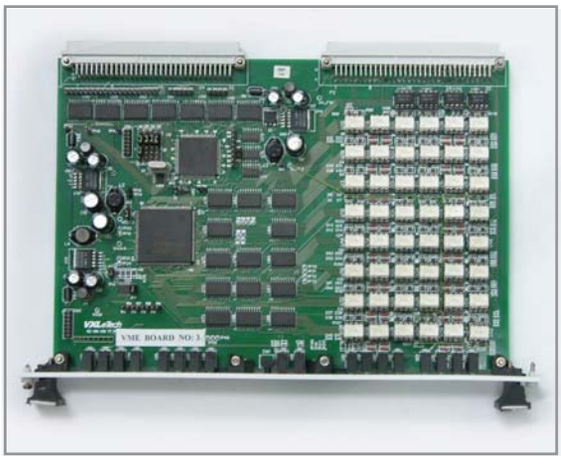
This Board is being designed on VME and IO bus and caters to 16 diff / 32 SE inputs. This board has 16 bit ADC and supports 10 KHz scan rate. On-board diagnostics is provided to detect the faults. An on-board DAC is used to generate analog outputs that are used for checking the ADC etc. The board also provides for limit checking on inputs.

Analog Output Board

The Analog output board is being designed on VME and IO bus and generates 8 isolated analog outputs. On failure of the system the outputs are put into fail-safe state which is programmable. The board has a 16 bit resolution DAC. The DAC outputs are fed back to an ADC for checking the healthiness.

32 bit High Performance CPU Board

This board has a 32 bit CPU running at 300 MHz, with 64 KB L1 cache, 1MB L2 cache,512 MB ECC protected DRAM, 128 MB Flash memory and 4 KB Non-volatile memory. Two serial ports and one Ethernet connection are also provided. One FPGA has been provided on board for user-defined functionality.



Dual Ethernet Communication Board

This is a VME bus based communication board with Dual Ethernet link support. The board has On-board processor for protocol processing. Ethernet 802.3 MAC protocol has been implemented in a FPGA.

Protocol Converter between VME & I /O Bus

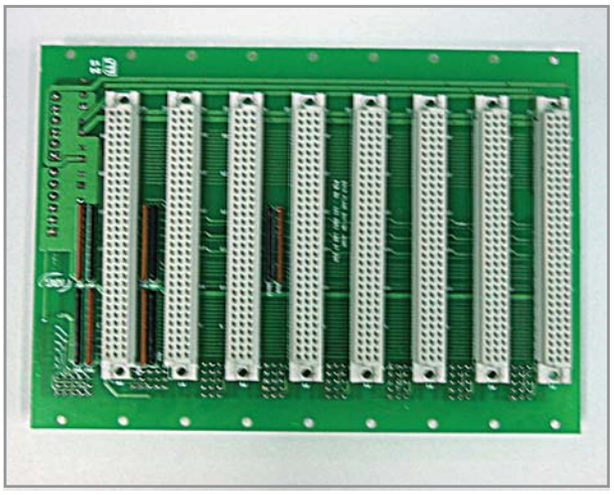
This is an interface board between VME and IO bus. This board converts the VME signals to IO bus signals and vice-versa. The logic has been implemented in a CPLD.

I/O Bus Backplane

This backplane is the media where all I/O boards are connected. This supports geographical addressing by way of jumpers for each slot.

Data Acquisition Board

This board caters to 8 Analog Inputs, 4 Analog Outputs, 8 Digital Inputs and 8 Digital Outputs. The board will have interface with VME and I/O bus. The Controller is being implemented on a FPGA using VHDL.

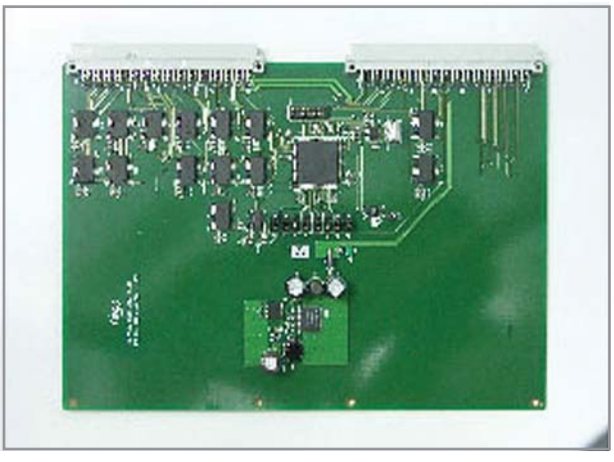


Remote I/O Board

This board caters to 8 Analog Inputs, 4 Analog Outputs, 8 Digital Inputs and 8 Digital Outputs. The board functions as a standalone board. A high performance processor on board will carry out the functions of data acquisition, processing and communication to a remote computer on an Ethernet link.

Enhancement of 'Ecbus' based Processor Board

16 bit microprocessor based double-euro format board earlier designed in Reactor Control Division is being upgraded to enhance its functionality. The upgraded board includes enhanced on-board memory and added on-board functionalities like supply monitoring and real-time clock. The board has been designed and the circuit diagram has been made. The prototype board is under fabrication at ECIL.



Development of Board for Interfacing PC-104 Bus based SBC Modules to 'Ecbus' based Boards

A family of microcomputer boards on proprietary bus called 'ECbus' was developed in Reactor Control Division. These development efforts ensured self-reliance on delivering reliable computer based safety critical systems of nuclear power plants. These boards in large numbers have been used in many safety critical systems of Kaiga 1 & 2, RAPS 3 & 4, TAPS 3 & 4 and are planned to be used for Kaiga 3 & 4 and RAPS 5 & 6. Now an interface board has been designed for interfacing SBC modules based on PC-104 bus to proprietary ECbus. With this interface board, the full family of ECbus based boards can be interfaced with the commercially available PC-104 bus-based SBC modules. This development provides a platform for developing customized I/O intensive embedded systems requiring high processing power. Use of PC-104 bus-based SBC module ensures upgradability and protects against chip obsolescence and supply denial. The prototype board has been fabricated, assembled and successfully tested. The board was upgraded by using CPLD. The board functionality was further enhanced by including Disc-on-Chip IC and an independent Watchdog timer with relay output.

G.Ganesh <ganeshg@barc.gov.in>

Reactor Regulating System for Apsara Reactor

Reactor Control Division is designing and developing a microcomputer-controlled Reactor Regulating System (RRS) for Apsara reactor. This system will replace the existing ON/OFF control with proportional control as part of Core Conversion Project of the existing Apsara reactor. The microcomputer hardware of prototype RRS has been assembled and tested. A front-end computer and operator's panel have also been designed and fabricated to provide field and operator's inputs to the prototype system. The control software including software for on-line diagnostics and network interface with Operator Information System have been developed.

To perform close loop testing of RRS a core simulator for Apsara reactor has been developed. This simulator software runs in a PC-104 bus-based processor board in the front-end computer and reads the rod position as input and generates the neutronic signals as output. The simulator communicates through serial

link with graphical user interface running on a PC. The GUI provides facility to change simulator parameters on-line and to view neutronic signals generated by the simulator.

C.K.Pithawa <pithawa@barc.gov.in>

Online Surveillance System for Emergency Cooling System of Dhruva Reactor

Emergency Cooling System (ECS) ensures operation of auxiliary cooling pumps on failure of main coolant supply in Dhruva reactor for removal of core decay heat.

The Online Surveillance of ECS is performed to check the healthiness of ECS logic by use of Finite Impulse Test (FIT) technique. The functions of FIT are to force finite impulses on certain combination of inputs on the ECS channel logic; and check its outputs and compare them with expected outputs and thus indicate fault if any, and also at card level. The testing is done on-line, periodically, without interfering with normal ECS functions.

Pre-detection of fault in ECS logic before it develops into a major failure enhances the availability and reliability of ECS System.

The Online Surveillance System is configured as three independent FIT channels for the three independent channels of ECS. At a time only one channel is undergoing test. The three FIT channels are connected to operator console on isolated serial RS-232 link, to provide operator interaction. The Online Surveillance System monitors and records the field inputs and outputs of ECS system. It records all test results and field input status, stores and displays them in various formats. One of the FIT channels has been commissioned with the ECS system of Dhruva in online testing mode and is undeyoing test.

B.B.Biswas <bbbiswas@barc.gov.in>

Alarm Annunciation System for Reactor and Power Plant Applications

Reactor Control Division has developed a new alarm annunciation system for nuclear reactors and power plants. Easy operation & maintenance were the key design considerations. The system has a distributed architecture and is based upon industry standard micro controllers. Some of the features are self-diagnostics, card-level redundancy, hot-swappable cards, isolated RS-485 serial communication, time stamping and printer port for online printing. The system is designed & developed to qualify for category-IB requirements. The technology for the same has been transferred to ECIL for manufacture & marketing of the system. Also, a low cost version of this system for commercial applications has also been developed.

Jose Joseph <jjoseph@barc.gov.in>

Programmable Logic Controller

A Programmable Logic Controller was developed in-house. The PLC uses Function Block Diagram (FBD as recommended by IEC-61131 part 3) for programming the control application. A set of Function blocks was developed for use in application development. Program editor and configuration utility software was developed for use on Windows platform. For supervisory control, the PLC provides MODBUS protocol on serial port.

A system using this PLC was commissioned in the vacuum controller system of EB – welding machine. Currently, the Function block library is being enhanced to include the analog control functions such as PID, Hysteresis etc. and to formally verify each function block. It is also endeavored to develop a MISRA-C compliant code generator from FBD.

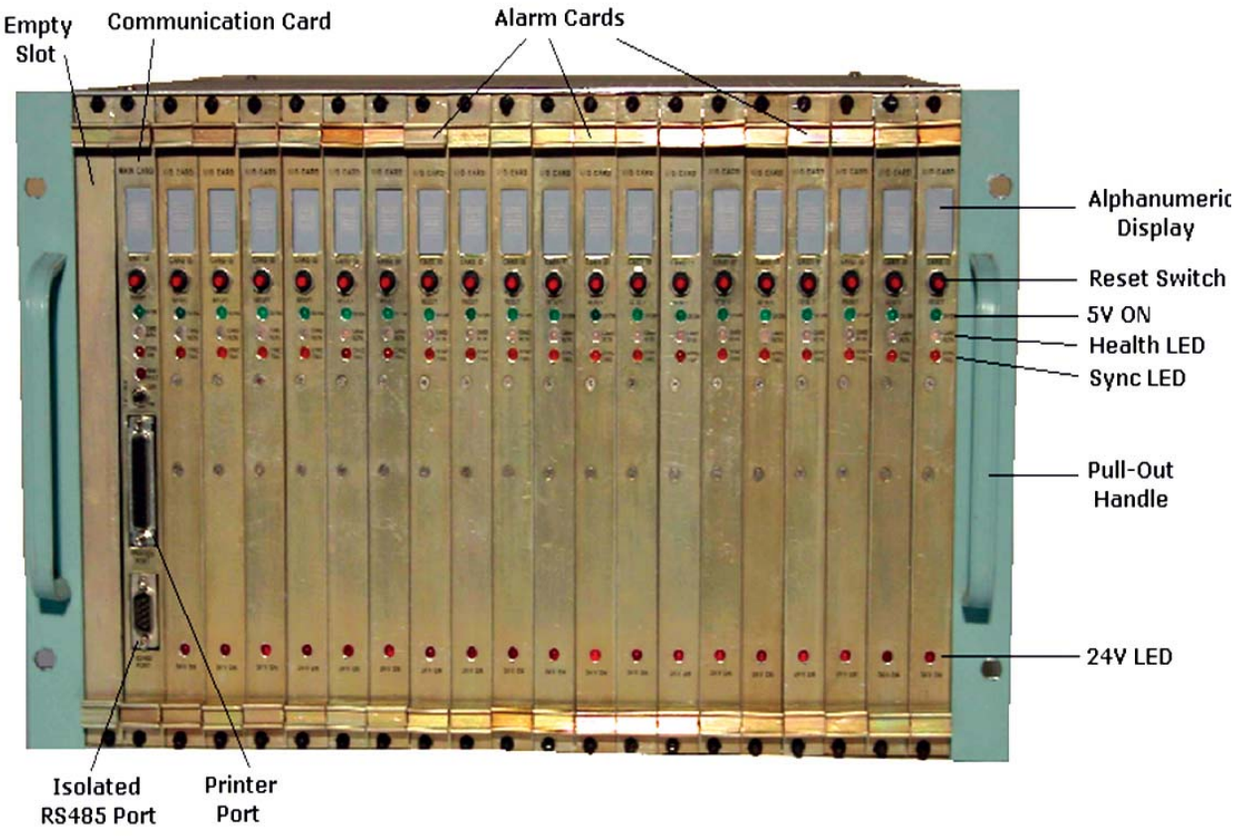
Jose Joseph <jjoseph@barc.gov.in>

System Software for Embedded Systems

Real Time Executive

Operating System (OS) is the core of the software as it controls the execution of processes. Real time systems need a real time operating system, which is multitasking, pre-emptive. In-house real time executive has been developed which satisfies the above needs, allows prioritizing tasks and is portable.

As the systems under development are class-IA and IB systems,



Programmable Logic Controller

the RTE has been made to qualify to this standard. It has also gone through verification and validation and code walkthrough.

Reliable Communication Software for Safety-Related Control Application

The design of computer-based control and instrumentation systems, particularly in Indian nuclear power plants have evolved over a period of several years and at this juncture these systems are not only providing plant information and monitoring but also playing a significant role in control and safety of nuclear power plants. Evolution of these systems has led to distributed and multi-nodal architecture. The data communication mechanism becomes the backbone in such architectures and it has to be reliable, robust and must meet the real-time requirements imposed by the application.

A reliable protocol, which is a subset of Transmission Control Protocol/ Internet Protocol (TCP/IP) has been specified and developed. This protocol is reliable, realtime and suitable for fast control application. The basic control functions of the system can depend on this protocol. It is also compatible with any third party TCP/IP, but still closed to any unknown connections. Thus, it is guarded against any unwarranted communication.

User Datagram Protocol (UDP) and Address Resolution Protocol (ARP) have been added to the software. The whole software alongwith the Ethernet card and drivers have been built and made available as firmware for control application.

This is in use at DPHS-PCS and at the Multinodal Reactor Regulating System (RRS) for TAPS 3 & 4. It is also in use at Apsara RRS.

Jose Joseph <jjoseph@barc.gov.in>
B.B. Biswas <bbbiswas@barc.gov.in>

■ 160KJ, 20KV Capacitor Bank for Rolled Joint Detachment in AHWR and EMF Equipment

Electromagnetic Forming (EMF) is the state-of-the-art technology for shaping and joining of metals. In this technique, forming is achieved without physical contact between tool and job piece. Hence, it has obvious merits over conventional processes such as brazing, welding, expansion, contraction, contour formation etc. Since the bond is achieved by impact/pressure, this method is ideally suited for joining/ welding of dissimilar metals. Apart from this, EMF has many other advantages such as repeatability, ease of operation, automation ease, high speed of operation etc.

G/S Repositioning Equipment

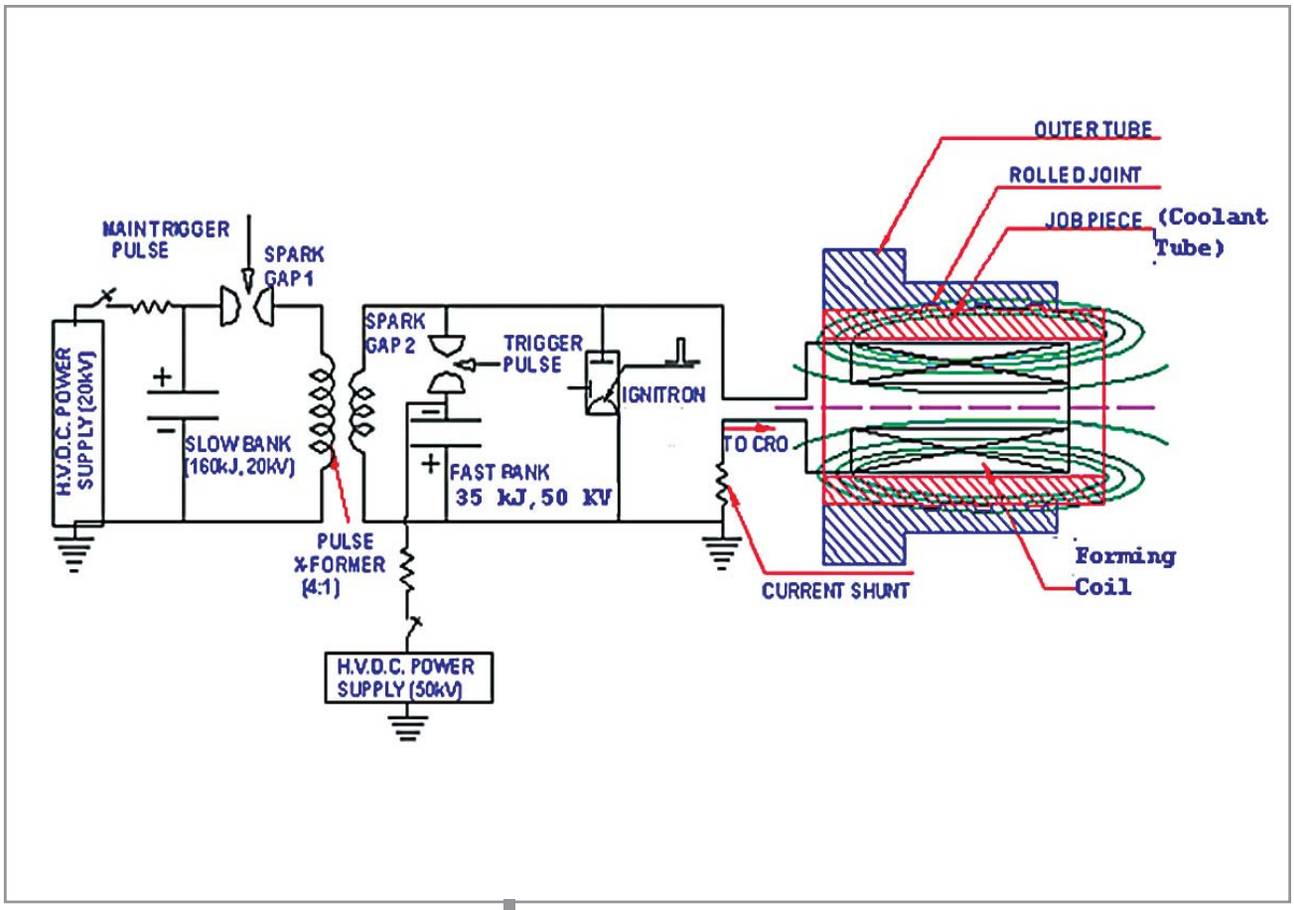
Accelerator & Pulse Power Division (APPD) and erstwhile Plasma Physics Division have played pioneering role in developing and nurturing this technology for more than two decades. The developments include applications such as Garter Spring (G/S) repositioning at NAPS-II and KAPS-I and feasibility demonstration for fabrication of Dhruva reactor fuel pins. Due to successful repositioning of G/S, the operating life of the fuel channels could be increased and thereby the cost of cutting and replacement of the fuel channel could be saved.

EMF Equipment for Rolled Joint Detachment

In the conventional EMF process, the classical force between the coil and job piece is repulsive in nature. However, in practice, situation is often encountered wherein an attractive force needs to be generated on account of inaccessibility. Detachment of rolled joint for AHWR is one such application. The problem of inaccessibility calls for innovative idea of achieving implosion of the tube (job piece) by placing coil inside it.

The implosion is achieved by a two capacitor bank system. The slow capacitor bank develops the magnetic field outside the coolant tube, which is made to collapse by discharging fast capacitor bank in opposite direction. This generates the implosive force. To achieve deformation/detachment in 7 mm thick zircaloy tube is a formidable task. Hence, as a first step, it was decided to build two capacitor systems, i.e. slow bank of 160 kJ, 20 kV and fast bank of 35 kJ, 50 kV for demonstrating the feasibility on copper / aluminum tubes of 1 to 2 mm thickness. The other important components of the equipment are high voltage charging power supply, pulse transformer, spark gaps, crow barring ignitron and forming coil.

It is planned to build a 160 kJ, 20 kV capacitor bank by upgradation of already existing 80 kJ, 20 kV capacitor bank. The synchronized switching of the sub-banks and switching of fast bank at a specified time delay constitute technological challenges in this endeavor. The design for this system is completed and work for the assembly will commence soon. After successful demonstration of the feasibility, the decision regarding building of full scale facility would be taken up. This technique would



Schematic of EMF Equipment for Rolled Joint Detachment.

serve as a viable and cost effective alternative for the already existing methods of mechanical cutting and R.F. heating.

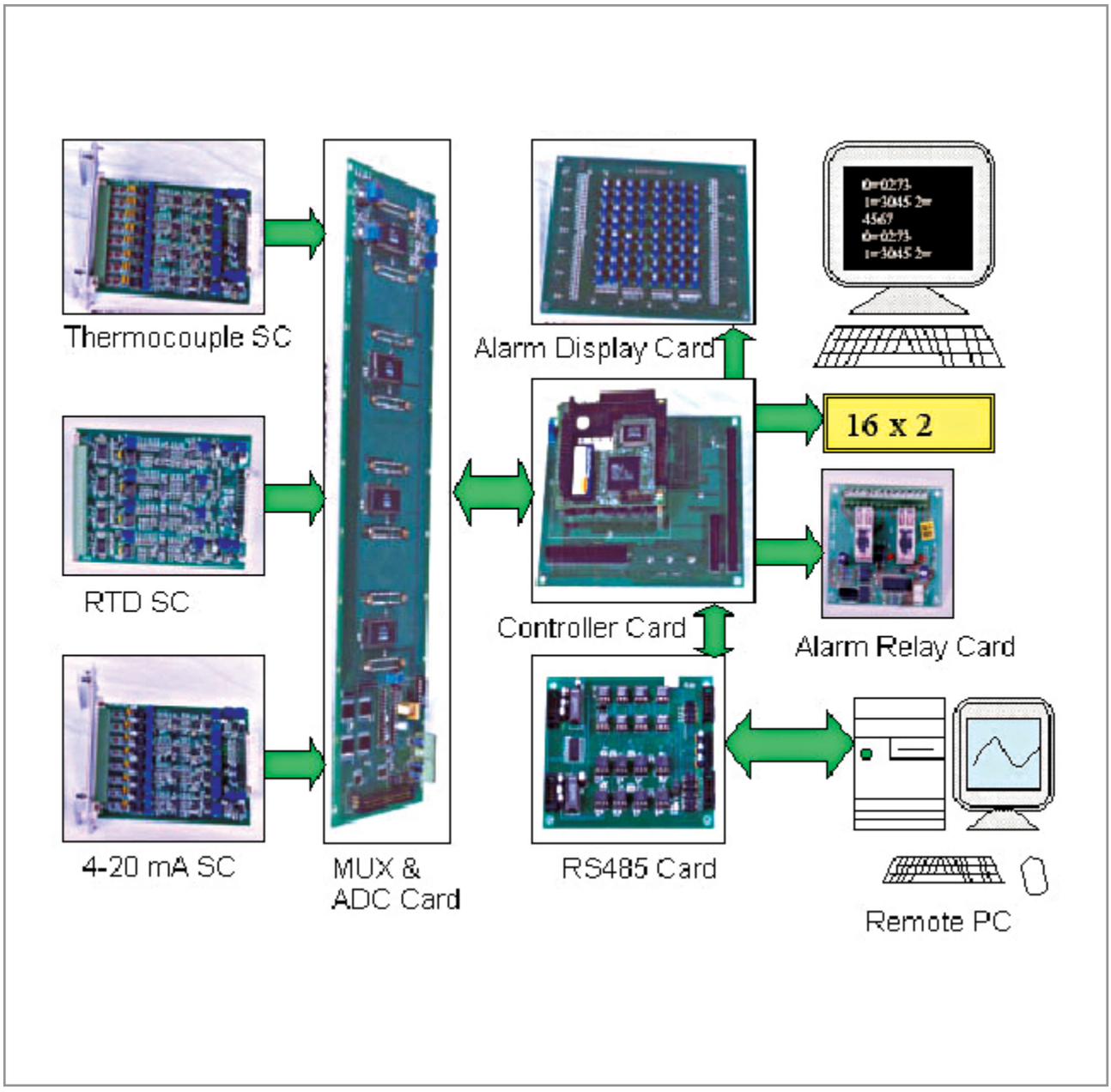
■ Graphite Reflector Temperature Data Acquisition System (DAS) for CIRUS Reactor

A 56 channel Graphite Reflector Temperature Data Acquisition System (DAS) for CIRUS reactor was designed, developed and commissioned.

Because of the concern for stored Wigner energy in the graphite lattice of the reflector, it was recommended by the safety committee to monitor the temperatures in the graphite reflector if the reactor was to be operated at full power after refurbishment.
The designed DAS monitors the graphite reflector temperatures in CIRUS reactor. It can acquire forty T type thermocouples, eight 4-20 mA, and eight PT-100 RTD signals at the rate of 500 msec for all the channels. The system consists of two major components a) Stand alone Data Acquisition System and b) Personal Computer (PC).

The stand alone DAS acquires the input signals, linearises and compensates for cold junction error. It also monitors the inputs for unsafe condition. The unit has provision for alarm annunciation relays, serial interface, VGA interface, and keyboard interface. The system has a capability to store data locally in case of unavailability of serial interface with the PC.

Personal Computer is connected to the Stand alone DAS over RS-422 serial interface. It communicates with the stand alone DAS unit for control and configuration of the stand alone DAS, data transfer and data presentation. The multithreaded PC



software incorporates serial communication, error detection, data storage, and GUI.

This system has been operational since October 2002 and the data gathered through this system has goosted the confidence of the operating personnel to operate the reactor power level at full power.

Data Acquisition System For Monitoring The Graphite Reflector TemperaturesIn CIRUS Reactor, K. D. Joshi, T. K. Saha, V. K. Handu, V. C. Sahni, **National Symposium on Nuclear Instrumentation** - 2004

Performance of Graphite Reflector Data Acquisition System in CIRUS Reactor, K. D. Joshi, T. K. Saha, M. M. Hita, V. K. Handu, MS&ESS, B.A.R.C, S. K. De, N. Ramesh, K. J. Vakharwala, R. C. Sharma, S. K. Agarwal, ROD, B.A.R.C., **National Symposium on Advances in Control & Instrumentation (SACI)** 2005

Kuldeep Joshi <kuldeep@barc.gov.in>

1.3 SOFTWARE RELIABILITY

■ High Integrity Software Development Lab and Resources for V & V

For development of future C&I systems, such as for AHWR, a High Integrity Software Development Lab equipped with Computer Aided Software Engineering (CASE) tools has been established for use in development of safety and safety-related software. This represents migration towards model-based development practices. Addition of more tools is an ongoing process. The Lab is currently equipped with tools that support full software design life cycle tasks covering requirements management, UML-based modeling tools, code generation, advanced testing strategies and configuration management.

Advanced static and dynamic analysis tools provide support for static and dynamic analysis of programs and C language safe subset compliance- checking as per MISRA C and MISRA C (2004) standards. Formal verification is important in relation to safety critical systems. The formal verification requires special skills. Expertise has been developed in the use of several formal verification tools like theorem provers, model checkers and modeling languages. The well known theorem provers like STeP (Stanford University), PVS (SRI International) and model checkers SMV (CMU) , nuSMV (IRST, Italy), SPIN (AT&T Bell Labs) and modeling languages like Esterel, Promela etc. have been extensively used in verifications and in building tools around them. Indigenously developed assertion checker ACE (for C and Ada) has been used in many important projects within BARC and other outside departments.

S. D. Dhodapkar <sdd@barc.gov.in>

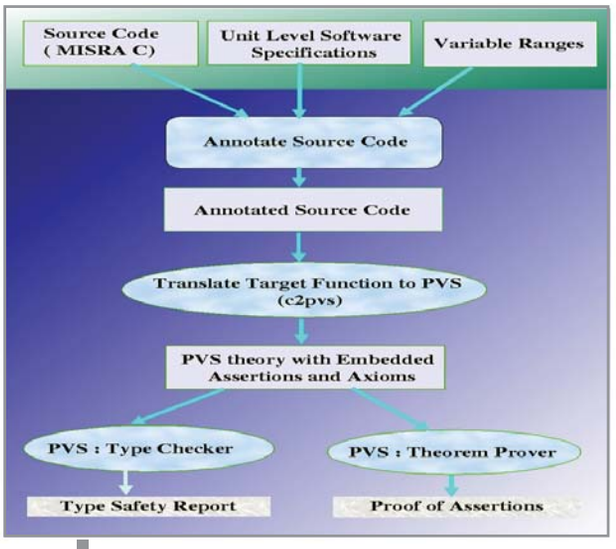
■ Formal Verification Tools

Tools for Model-based Verification

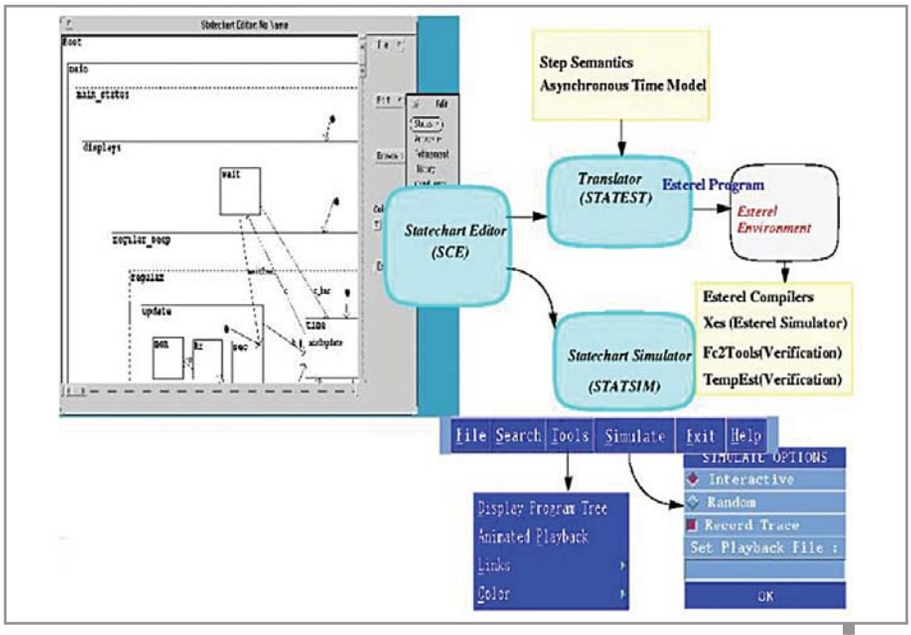
The graphical notation of *Statecharts* is popular for modeling of reactive systems. Although the semantics of *Statecharts* is well defined it lacked tool support for verification. In order to enable formal verification of *Statecharts models,* a tool has been developed to translate them to *Esterel.* Based on this work, a Programming Environment for Real-time Systems (PERTS) was built to enable modeling, simulation and verification of reactive software such as one present in various types of controllers. In later work *Statecharts* notation was extended with primitives for modeling *Communicating Statecharts* (CS). The CS notation can be used to model distributed reactive systems communicating to each other through channels. A translator called *CSPROM* has been developed to convert CS into *Promela*, a modeling language, so that models can be formally verified using a SPIN.

Static Assertion Checkers

Static Assertion Checkers are very advanced tools based on formal (mathematical) method and used for functional verification of software. A tool called Assertion Checking Environment (ACE) has been developed for verifying programs written in C language against their specifications, which are captured as *annotations* in the source code. ACE which primarily consists of a tool called *c2spl*, translates, annotated C code (compliant to safe-subset MISRA-C) into a formal notation called "*spl*". Theorem-proving tool STeP (Stanford Temporal Prover) is then used to obtain proofs of the assertions. An advanced version of this tool called ACE II is under development. This version of assertion checker will use theorem-proving tool called PVS (from Stanford Research Institute, SRI) as back-end verification engine. ACE II based verification in addition to providing capability for assertion checking, will also have capability to detect run time errors viz.



Formal Verification using ACE II



Programming Environment for Real-time Systems (PERTS)

array index out-of-range, overflow, division-by-zero etc. in MISRA compliant C programs. This is accomplished by using type-checking supported by PVS.

Object Code Validation

An Object Code Validation (OCV) Scheme and associated tools were developed as part of the sponsored project from Aeronautical Development Agency. The OCV method is designed to prove correctness of object code generated by Ada compilers (non optimizing mode). It uses *Translation Validation* technique wherein one tries to prove that a given translation by the compiler is correct rather than proving that compiler (translator) always produces correct translation. *OCV* scheme treats Ada source program and its object code (for i960 processor) as two entities whose *'equivalence'* has to be demonstrated. For this safe sub-set of Ada called SPARK Ada and i960 programs are translated to a common semantic framework (*spl*). Two translators *ada2spl* and *i9602spl* developed as part of this work accomplish this. The final demonstration of 'equivalence' is achieved using theorem prover STeP (Stanford Temporal Prover). The work was done in collaboration with School of Technology and Computer Science, TIFR, Mumbai.

Formal Verification of Timing Properties of Real-time Systems

Most real-time systems are required to perform activities in a time-bound manner. The timing behavior of systems (model) as well as timing specifications (properties) can be captured formally in a logic called Interval Duration Logic (IDL). IDL is a highly expressive logic but no algorithm exists for checking whether the properties hold over the model, in general.

However, as in the Bounded Validity Checking approach the correctness of specifications can be formally checked for a finite number of steps specified by the user. If a system-trace of violation of specification (counter-example) is found then the verification process ends else a higher bound on number of steps is tried.

A SAT solver called ICS (SRI International) was used to prove the correctness of IDL properties for finite bound on number of steps. A translator called *idl2ics* has been developed to encode IDL properties and models in the input language of ICS.

S. D. Dhodapkar <sdd@barc.gov.in>

Formal Verification of Software

Formal Verification of Software of Mission-critical Embedded Software

ACE tool developed for use in verification of safety critical software used in reactors was used for verification of mission critical software from ADA and ISRO. The software of GUH system a mission-critical embedded system of Light Combat Aircraft (LCA) was completed using ACE. The project was sponsored by Aeronautical Development Agency (ADA), Bangalore. Similarly formal verification of onboard FDIL software for VSSC, ISRO was also completed using software called *ada2spl* developed in BARC as part of OCV project. The work was done in collaboration with Centre for Formal Design and Verification of Software, IIT, Bombay.

Formal Verification of Process Interlock Software for LWR Application

The software programs for implementing process interlocks, which were generated using a code generation tool, were subjected to *formal verification*. The code-generating tool takes graphical specifications of the interlock logic as input and generates C code. The C code so generated was checked against its specification using the static assertion checking technique. The formal specifications were derived from the logic input to the code generator. The specifications were then used to annotate the code with assertions. The verification was performed by using ACE.

Formal Modeling and Verification of FIT-ECS System for Dhruva Reactor

Mathematical modeling of the contention logic of FIT-ECS System for Dhruva was carried out based on the informal system specification. The model was built in Esterel and SMV. The model was then formally verified against the required system behavior (some safety critical properties), which helped validate the system specification.

PERTS: An Environment for Specification and Verification of Reactive Systems, A.K.Bhattacharjee, S.D.Dhodapkar (BARC), S.Seshia, R.K.Shyamasundar (TIFR). **Reliability Engineering and System Safety,** Vol. 71 No. 3: March 2001

Assertion Checking Environment (ACE) for Formal Verification of C Programs by Babita Sharma, S.D.Dhodapkar (BARC), S.Ramesh, (CFDVS, IITB), **Reliability Engineering and System Safety,** Vol. 81, 2003

Bounded Validity Checking of IDL by Babita Sharma (BARC), Supratik Chakraborty (IITB) and Paritosh Pandya (TIFR), **11 International Conference on Tools and Algorithms for the Construction and Analysis of Systems (TACAS 2005),** Edinburgh, UK, 2005

Formal verification of Reactor Process Control Software using Ascertion Checking Environment, Babita Sharma, Sowmya Balaji, Ajith U.J., A.K. Bhattacharjee, S.D. Dhodapkar. **SACI - 2005,** BARC Mumbai

S. D. Dhodapkar **<sdd@barc.gov.in>**

2. ACCELERATORS AND ELECTRON BEAM TECHNOLOGY

INTRODUCTION

Development of various DC, RF and pulsed electron accelerators for industrial and strategic applications and their RF control electronics are major R & D activities of BARC. Electron beams with beam energy in the range of 0.2 to 10 MeV and up to 150 kW have found a large number of industrial applications such as modification of bulk polymers, cross linking of plastic film, sterilization of medical products and food irradiation. Pulsed High Power Electron Beams with peak power of several Gigawatts are useful for generating flash X-rays ,high power microwaves and pulsed neutron and ion sources. Electron Beam (EB) Technology is another major thrust area, which has extensive applications in the nuclear Industry as well as other industrial applications. Electron beam machines operating over a wide range of power levels, from a few kilowatts to a few hundreds of kilowatts, have been indigenously developed at BARC for welding, melting and non-thermal processing. Significant developments in the fields of Accelerators, RF control electronics and EB technology are summarized in this chapter.

2.1 ACCELERATOR TECHNOLOGY

During the last few years BARC has been involved in the development and utilization of various DC, CW and GW pulsed electron accelerators for industrial and strategic applications. Electron beams with beam energy in the range of 0.2 to 10 MeV and up to 150 KW have found a large number of industrial applications such as modification of bulk polymers, cross linking of plastic film, foam and cables, degradation of scrap Teflon and cellulose materials, sterilization of medical products and food irradiation. Pulsed High Power Electron Beams with peak power of several Gigawatts are useful for generating (i) Flash X-rays (FLX), (ii) High Power Microwaves (HPM), (iii) Pulsed Neutron Sources (PNS) and (iv) Pulsed Ion Sources. Keeping these applications in mind, the development of industrial electron accelerators and GW pulsed accelerators have been taken up as part of the "Indigenous Electron Accelerator Development Programme at BARC". The following subsections describe the power sources and control /safety interlock systems for the above accelerators.

■ 200 KV Compact Pulse Generator

The Accelerator and Pulse Power Division (APPD) of BARC has been involved in the development of high power high voltage pulse generators in connection with relativistic electron beam generation and its applications. Some of the applications are: high intensity flash X-ray generation, microwave generation, pulsed neutron generation, high voltage insulation studies etc. Most of these applications require high peak power and preferably constant amplitude pulses of tens of nanosecond duration. This activity was started in the late seventies. A number of equipment have been built and put into operation. Among them, the comparatively compact and portable generators are based on Pulse Forming Network (PFN) Marx scheme. First of its kind was a 300 KV, 1.5 KA, 100 ns PFN Marx generator developed for flash X-ray generation for Terminal Ballistic Research Laboratory, Chandigarh. Later on a number of PFN Marx generators were built with ratings up to 400 KV, 3 KA and pulse duration of the order of 80 ns. Apart from the high current, short duration pulse generators based on Marx scheme, APPD has also developed generators with moderate current and pulse durations. One such equipment is a 150 KV,150 A, 5 ms pulse generator used for electron beam pumping in CO_2 Laser system at the Laser and Plasma Technology Division. This generator is based on a helical pulse forming line as storage element implemented for the first time in the world.

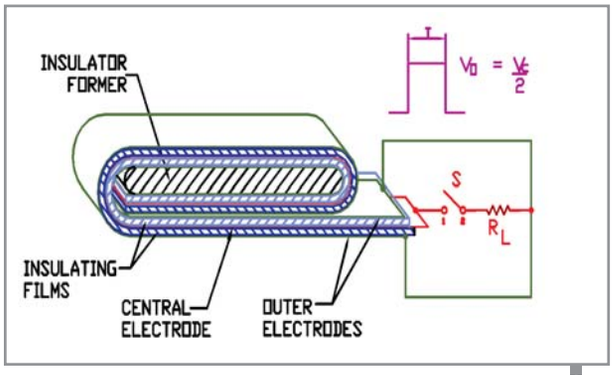
For the PFN Marx generators, basic energy storage elements used were Barium Titanate capacitors, which suffered from reliability problem, when used for high current discharge applications. Hence, efforts were made to procure film insulated energy storage capacitors. However, it was realized that achieving low inductance and high discharge current from a conventional capacitor is highly difficult. Hence, we have developed an unconventional pulse forming element called Folded Pulse Forming Line (FPFL) to replace the PFN module.

The FPFL is an energy-storage cum pulse forming element, which works on the principle of parallel plate transmission line. It is made of conductor and insulating films of desired dimensions dictated by the pulse parameters, wound on insulating former for making it compact. Photograph of the FPFL capacitor and the schematic diagram of the FPFL module are shown below. This module is rated for 10 J and can deliver 7.5 KA on a matched load at its rated charging voltage of 30 KV.

FPFL capacitor rated 30 KV, 10 J.

It has nearly three times the energy and peak power output, compared to a PFN module using Barium Titanate capacitor

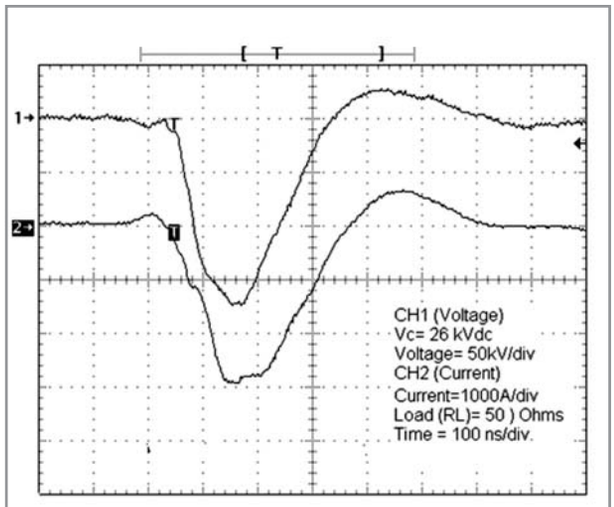
module of similar size. The photograph of the FPFL generator rated for 180 KV, 6 KA, 100 ns and its output voltage and current waveforms are shown.



Schematic Diagram of the FPFL Module

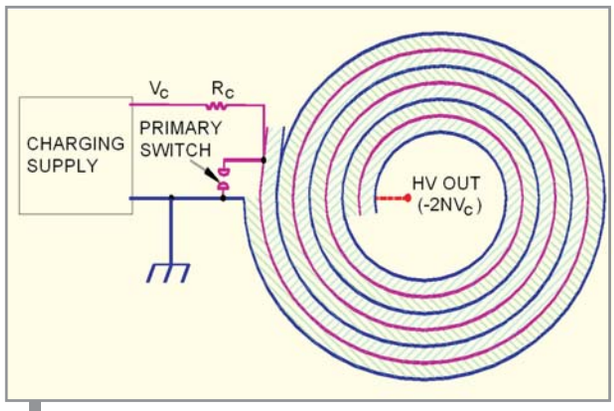
Efforts are on for developing further compact and more rugged systems, which can be conveniently used for field applications. As a result we are in the process of developing a new type of pulse generator called Spiral Generator. It works on the principle of a rolled-up Blumlein in which one of the two parallel transmission lines charged by a DC power supply is inverted by closing a spark-gap switch. Output voltage multiplication factor and energy efficiency depends on the number of spiral turns, dimensions of the winding and inductance of the spark-gap

180 KV, 6 KA, 100 ns Marx Generator Assembly



1- Load Voltage- 170 kV peak
2- Load current- 3kA peak
Time Scale- 100ns /div., Load: 50 Ω

Marx Generator Output
Voltage and Current



Schematic Diagram of the Spiral Generator

switch. Compared to Marx generators it is simple in construction and more compact. Prototype trials have been conducted to study the voltage multiplication efficiency. An improved prototype generator is in an advanced stage of fabrication. Assembly of the generator has been taken up and expected to be completed shortly.

K.Nanu <knanu@barc.gov.in>
Dr.K.V.Nagesh <kvnag@barc.gov.in>

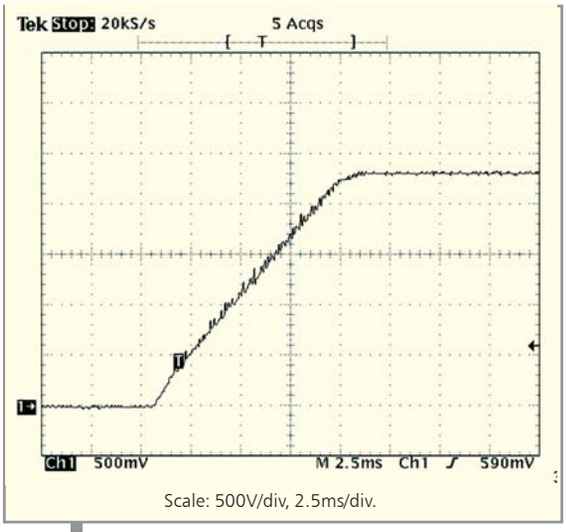
20 MW Solid State Pulse Power Modulator for 200 KeV Induction LINAC

A 250 J, 100 Hz solid state pulse power modulator has been developed at APPD for a 200 KeV, 5 KA, 50 ns, 1 GW LINAC. The solid state modulator generates a peak power of 20 MW, which is further processed by magnetic pulse compression and pulse shaping networks to produce the final 1 GW peak power pulse output. As this modulator employs fully solid state switching, maintenance problems associated with spark gaps or thyratrons are completely eliminated. The modulator comprises of a 20 A, 3 KV constant current charging stage followed by a 250 J Command Resonance Charging (CRC) stage. A microcontroller based control system is used to coordinate the charging and CRC operations.

Charging Power Supply
for the Modulator

The charging unit is designed around 30 KHz, IGBT based PSPWM inverter. The inverter output is stepped up by a ferrite cored step up transformer to 5 KV. The transformer output is rectified and fed to the intermediate energy storage capacitor of the CRC stage through a 3 mH output choke. Once the charging voltage reaches the desired level of 2.5 KV, the inverter operation is terminated by the control system and the command resonant charging stage operation is initiated. The CRC stage operation consists of discharging of the intermediate energy storage capacitor through a low inductance step up transformer to charge the 1.25 μF output capacitor to 20 KV within 20 μS.

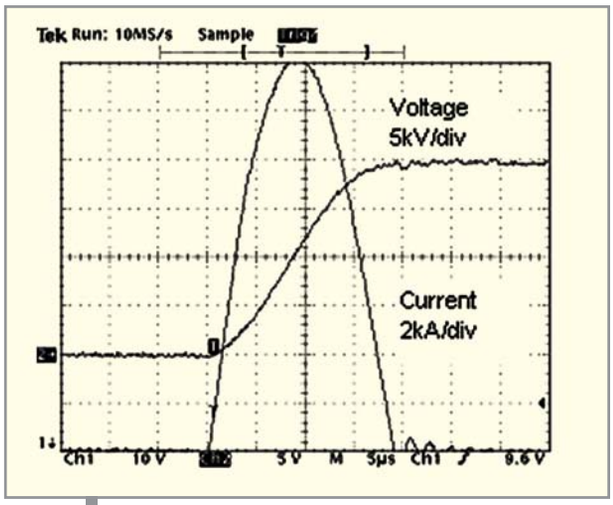
A laser triggered high current thyristor is used as the discharge switch. Each discharge operation produces a half sinusoidal current of 16 KA peak through the switch, resulting in transfer of 250 J to output capacitor producing 20 MW peak power. Major size reduction has been obtained by the use of high frequency operation of the charging supply and by the use of



Scale: 500V/div, 2.5ms/div.

Charging Voltage Waveform

ferrite and amorphous core materials in the circuit. At present the system is being tested in single shot mode at the required energy level of 250 J and the charging voltage and output voltage of transformer are shown in the figure.



Test Results of the Pulse Power Modulator

Rehim N Rajan <rehim@barc.gov.in>
Dr.K.V.Nagesh <kvnag@barc.gov.in>

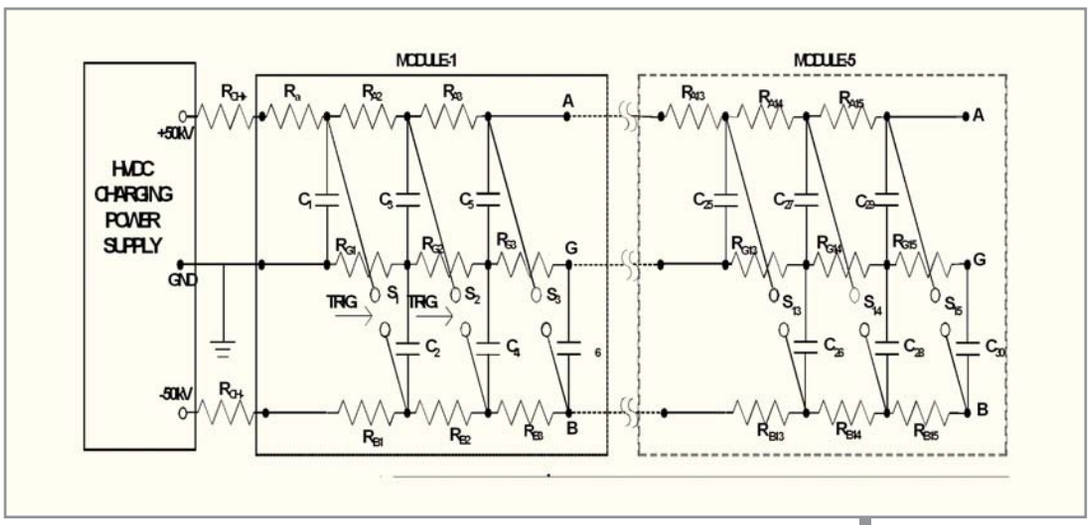
Design and Development of 1 MV Plus-Minus Charging Type Marx Generator for KALI-5000 System

The applications of high voltage pulse power systems are no more limited to testing of insulators and equipments. The scope of fast pulse generators has now extended to production of high power pulsed beams of electrons, ions, lasers and High Power Microwaves (HPM). In order to produce high voltage pulses, the Marx generator is one of the best-known and widely used techniques for the combination of short rise time and low output impedance, large energy, high efficiency and waveform flexibility. The essence of the Marx principle is the transient series connection of a number of electrostatic energy storage capacitors. As designs of Marx generators are made compact, two problems arise: breakdown hazards increase and the inter-stage capacitances increase with the result that 2 electrode gaps can be triggered by operating them very close to self breakdown, thus reducing the pre-fire safety factor. Therefore, it is necessary to devise improved arrangements for triggering the series connecting switches and accommodating the higher electric stresses in large, compact Marx generators.

Typical configuration of Marx generator with peak ratings of 1 MV and 25 KJ, based on plus-minus charging is shown in the figure. The charging resistors (R) of conventional Marx is replaced by inductors (L) to reduce power loss and heat production in the oil insulation used for the Marx generator, and allow faster charging of Marx capacitors, thereby, enhancing the repetitive pulse capability of Marx.

The main advantages of plus-minus charging are as follows:

a) The number of spark gaps is halved as compared to a conventional Marx of single polarity charging. This results in lower inductance, less complexity and increased reliability.



Schematic of Plus Minus Marx Generator of KALI-5000 System

b) It enables efficient use of three electrode triggered gaps with center electrode held at earth potential, thereby, producing uniform field and high insulation value.

c) Compared to single polarity 100 KV charging, the insulation requirement to ground in the present case is only 50 KV.

KALI-5000 System (1 MV, 40 KA, 100 ns, 5 KJ)

This Marx generator is divided into five modules, rated 300 KV each. These are mounted on a trolley so that all these components are mounted on a 1400 mm long, 1200 mm wide and 30 mm thick perspex sheet with sufficient track distance from the ground

Marx Module Side View

plane as well as from capacitors, spark gaps and charging resistors. Each module has three spark gap switches, 6-capacitors of 0.7 µF, 50 KV ratings, three ground resistors of 20 KΩ and 6-charging resistors of 2.5 KΩ. The charging path is through a flexible cable and the discharge path is through a 50 mm S.S. tubular pipe with rigid connections between two modules, which act like a jumper of 300 KV. Output connection of the Marx generator is taken through a 100 mm corona free structure through the center of a 1 m diameter port of the tank. This tank is provided with transformer oil filling and degassing facilities for insulating the parts of Marx generator during operation. All spark gap switches are kept under high-pressure nitrogen gas. This system has been tested with REB diode assembly at 20 KV charging with an output of 600 KV (pk), 500 ns (FWHM). It could be moved in and out of its stainless steel enclosure of 3 m length, 1.4 m width and 1.5 m height.

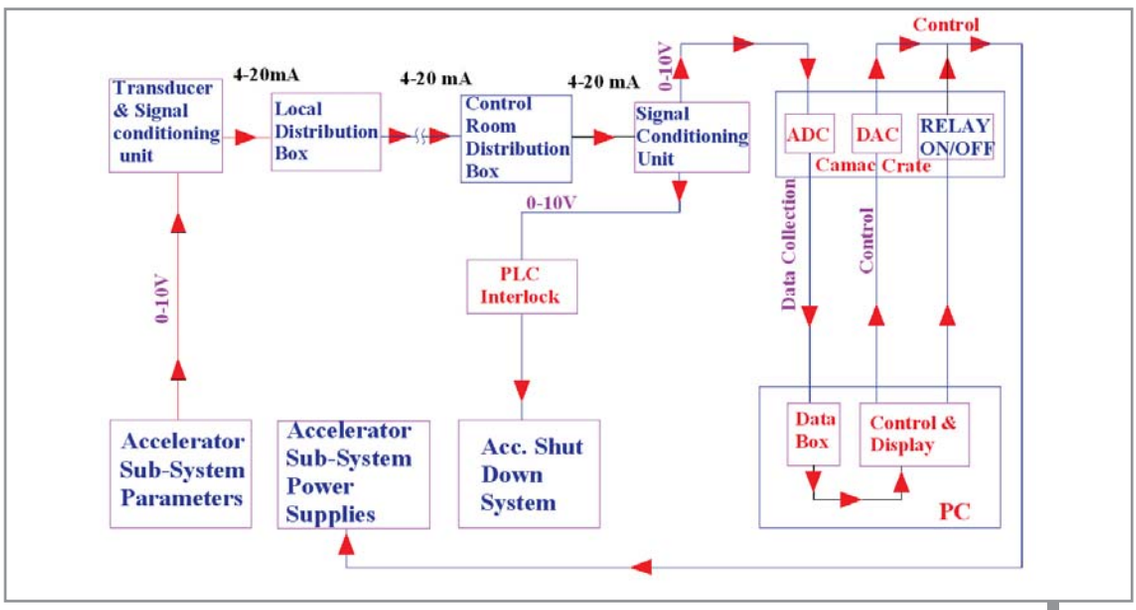
Dr. Archana Sharma <arsharma@barc.gov.in>
Dr.K.V.Nagesh <kvnag@barc.gov.in>

Computer Control Systems for Industrial Accelerators

APPD has developed a computer control system for its three industrial electron accelerators, the 500 KeV, 10 KW Cockcroft-Walton, the 10 MeV, 10 KW RF linac and the 3 MeV, 30 KW Dynamitron DC accelerator. The computer control system has a number of new features:

i) Common architecture: The same control system can be used for any of the 3 accelerators by changing some data in the data box. The hardware remains the same.

ii) Push button operation: In this feature, the entire accelerator can be switched on /off by pressing a START / STOP button.



Block Diagram of the Control Circuit using CAMAC based System.

A View of the Control Room of the 10 MeV Accelerator

The subsystems are internally linked in the software and are switched on sequentially with appropriate time delays, after checking for interlocks for the machine safety at each step. This will aid in decreasing the operator manpower requirements. Both features are new in accelerator control system development. Two versions for the hardware are available, one which uses a CAMAC crate with ADC, digital input/output and DAC cards for data acquisition and another which uses commercially available PC plug-in cards for the data acquisition. A micro-controller based control system is also under development in the division. This is suitable for a distributed system, for example, an accelerator complex or industrial plant, which is spread over several acres and where signals over large distances are to be collected and controlled. A local micro-controller sends the signal through a CAN interface or a CAN RS-232 link between the subsystems and the computer. The use of local micro-controllers eliminates signal noise and pick-up during transmission and communication. The data acquisition cards (ADC, DAC, digital input/output cards), a RS-232 to CAN (vice-versa) converter card, the CAN software drivers, BIOS and data acquisition software drivers for the SAB 80C535 micro-controller have been entrely designed in the division. A complete system incorporeting the above features has been fabricated and has been tested on a prototype ECR microwave ion source.

Aravind jain <arvjain@barc.gov.in>

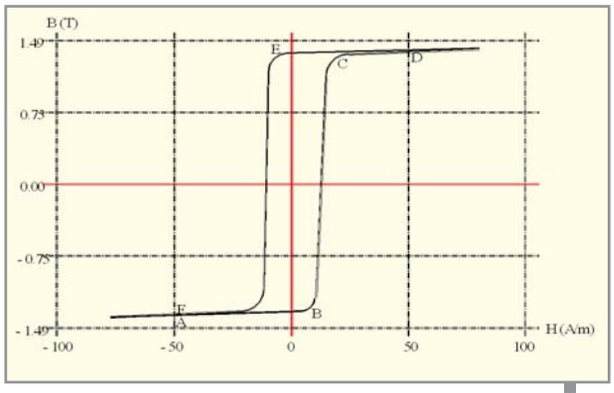
Magnetic Switches for Pulse Compression In 200 KeV Induction LINAC

The fundamental purpose of pulsed power systems is to convert a low power, long duration input pulse into a high-power, short duration output pulse. In the ideal case of a lossless system, the input and output energies are equal and a 1 KW, 1 s input pulse is compressed into a 1 GW, 1 ms output pulse. To make pulse power technology more adaptable to industry, it is required to have high average power and higher pulse repetition rate output. Earlier, pulsed power accelerators suffered from the limitations of low repetition rate of switches like spark gaps but the advent of amorphous magnetic material with high flux-swing has dramatically altered the scenario. The equation governing the design of magnetic pulse compressors is as follows:

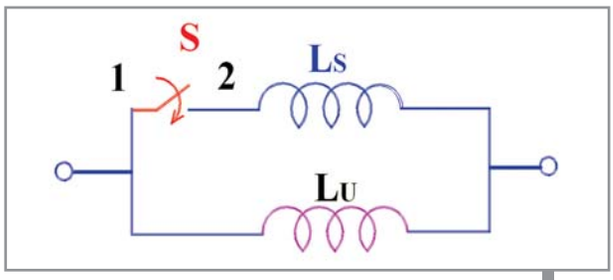
$$\text{Core capacity: } \int V_0.dt = N.A.\Delta B;$$

where N is the number of turns, A is the area of core cross-section, ΔB is the flux change and t is the duration of voltage pulse, when core gets saturated or changes from $-B_r$ to B_s. The basic B-H characteristics and equivalent circuit of the magnetic switch are shown below. In the present magnetic pulse compressor, toroidal cores (160/240/25 mm) of amorphous magnetic material 30 KCP are used. Amorphous core data in the operating power (MW-GW) and frequency regime (few MHz) were investigated viz. permeability (>10,000), flux-swing (~3T) and core-loss at desired dB/dt (rate of flux swing) and magnetic

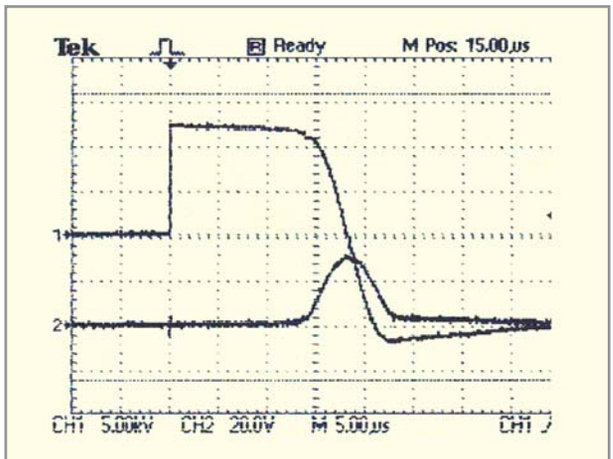
switches were designed and developed to compress the pulses from 20 KV, 20 µs to 200 KV, 100 ns. Typical voltage and current wave-shapes of magnetic switching are presented for 20µs /5µs switch.



Typical B-H Characteristics of Magnetic Switch



Equivalent Circuit of Magnetic Switch



1- Load Voltage- 12 kV peak, 2- Load current- 3 kA peak Time Scale- 5 μs/div.

Typical Voltage(1) and Current (2) waveforms for 20μs/5μs Magnetic Pulse Compression Switch

Magnetic Pulse Compression Switch for 20µs/5µs

Dr. Archana Sharma <arsharma@barc.gov.in>
Dr. K.V.Nagesh <kvnag@barc.gov.in>

50 KV, 1 A, Gun Modulator for 10 MeV, 10 KW RF Electron LINAC

The 10 MeV, 10 KW RF Electron linac for industrial applications is in an advanced stage of completion at the Electron Beam Centre, Kharghar, Navi-Mumbai. A thermionic emission based electron gun, in triode configuration, used as the injector to the linac is required to produce a maximum pulsed current of 1 Amp, at an energy of 50 KeV ± 10% with pulse width of 10 ms and repetition rate of 400 Hz. A line-type pulsed modulator which generates the required pulsed voltage of 50 KV has been designed, developed and tested on the electron gun. The line-type modulator consists of a HVDC power supply, charging choke, charging diode, 11-stage pulse-forming network (PFN), hydrogen thyratron switch, pulse transformer and associated control circuitry. The operation of the line-type modulator consists of the charging and discharging cycles. During the charging cycle, PFN capacitors are charged to twice the supply dc voltage, due to resonant charging. In the discharge period, the thyratron is triggered, thereby discharging the PFN capacitors through the PFN inductors and the primary of the pulse transformer. The voltage across the primary of the pulse transformer is a pulse of 10 ms width at 5 KV. A turns-ratio of 1:10 is used to step up this voltage to the required level of 50 KV.

Gun Modulator for 10 MeV RF LINAC

The major challenge in this project involves the design and development of the pulse forming network and the pulse transformer. PFN has been developed using indigenously available, low-cost components. The 1:10 pulse transformer was fabricated using 4-mil Si-steel laminated core, with Kapton and Mylar insulation between primary and secondary windings. An output of 50 KV was measured across a matched resistive load, for a primary voltage of ~ 5 KV. The pulse width achieved is ~10 μs at a pulse repetition rate of ~ 400 Hz. The rise time is ~2 μs, while the voltage flatness is within ± 4%, as against the requirement of ± 10%. The modulator has been tested on the actual electron gun. At a filament power of ~ 400 watts, an output electron beam current of 1.2 Amp has been measured at a cathode voltage of 50 KV.

Kavita Dixit <**kavidi@barc.gov.in**>

■ Power Source Development for 3 MeV, 30 KW DC Accelerator

APPD has taken up the development of a 3 MeV, 30 KW DC accelerator to be commissioned at EBC, Kharghar, Navi-Mumbai. A 3 MV, 10 mA DC power supply is being developed at APPD for this accelerator. This power supply is based on a parallel fed voltage multiplier scheme operating at 120 KHz input source. Parallel fed voltage multiplier scheme has been adopted because, it is capable of generating the required ultra high DC voltage at high power with added advantages of better regulation, less

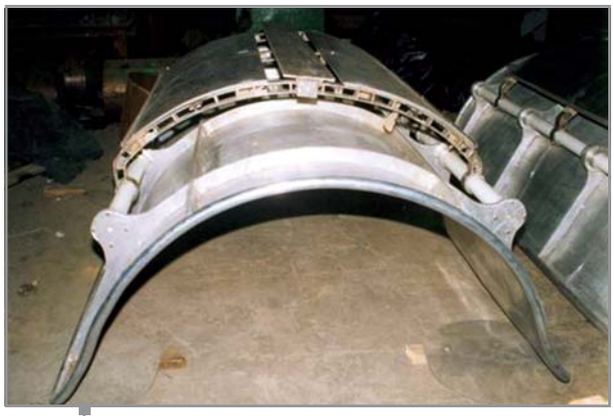
Power Supply Room at EBC, Kharghar, for
3 MeV Accelerator

ripple, fast response time, less components and better reliability in comparison with the conventionally used Cockcroft-Walton generator. This type of power supply is being developed for the first time in our country. Installation of equipment in the power supply room at EBC, Kharghar is shown in the figure. A thyristor controlled converter converts electrical power from 3 phase mains into 0-10 KV, 10 A DC. The 0-10 KV DC is inverted to 120 KHz using a vacuum tube oscillator.

It in turn is stepped up to 150 KV – 0 – 150 KV by a resonant tank circuit comprising of an air core transformer and capacitance formed by the feeder RF electrodes of the voltage multiplier. The RF voltage present on the RF electrodes is coupled to the voltage multiplier column corona guards, through the inter electrode capacitances between RF electrodes and corona guards. These RF power on the corona guards are rectified and cascaded for achieving the required output voltage of 3 million volts. Power input from mains is fed through an AC stabilizer capable of maintaining input to the system within 0.1% against variation in the mains voltage.

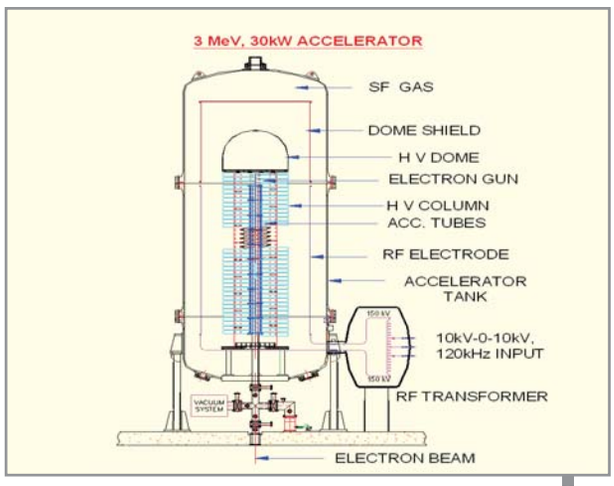
The voltage multiplier located around the accelerating column in the accelerator tank uses common SF_6 gas insulation at 6 Kg/cm^2. Support insulators of the voltage multiplier column are 3.3 m tall acrylic fabricated in single length by chemically joined sheets. Stainless steel cross members are provided for mechanical integrity. The layout schematic of the voltage multiplier assembly inside the accelerator tank is shown in the figure.

120 KHz, 50 KW Oscillator Assembly for
3 MeV Accelerator

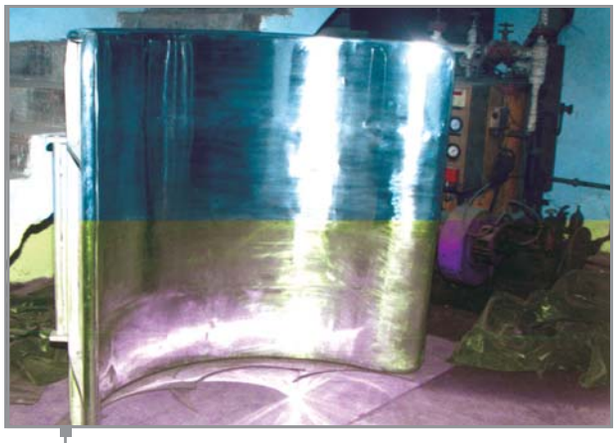


RF Electrode Assembly of
3 MeV High Voltage Column

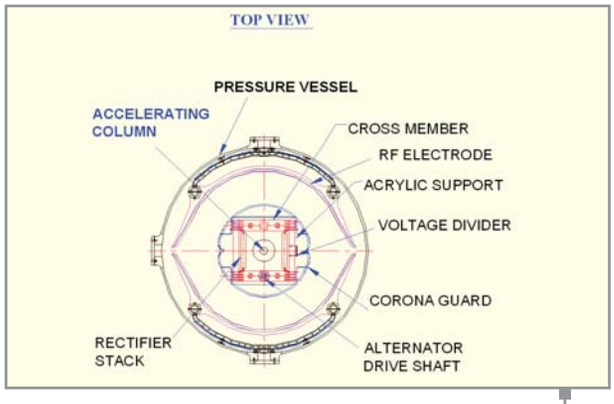
Shapes and geometries of the high voltage dome, corona guards, RF electrodes, dome shields, RF transformer, rectifier stacks, voltage divider etc. are quite complex, since they have to withstand high electrical stresses in the system. RF electrodes are semi-circular in shape and have sizes of 815 mm inner radius and 2.85 m height. It is made out of 3 mm thick Al 6351 alloy. Mechanical and electrical integrity to these electrodes are ensured by appropriate stiffeners.



Cross-Sectional View of the High Voltage
Multiplier Column of 3 MeV Accelerator

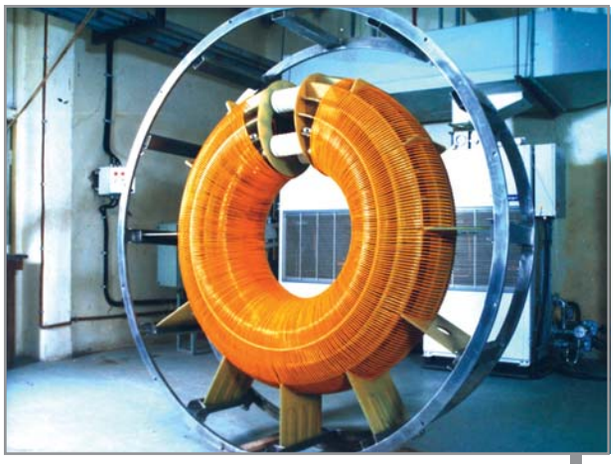


Dome Shield Assembly of 3 MeV High Voltage Column



Top Cross-Sectional View of the High Voltage
Multiplier Column of 3 MeV Accelerator

Electrodes are supported on Delrin insulators to achieve the required 150 KV electrical isolation from the accelerator tank. One pair of dome shield having shapes somewhat similar to RF electrodes is provided to smoothen out the electric field concentration on dome terminal and RF electrodes.



150KV-0-150KV, 10 MVA RF Transformer
of 3 MeV Accelerator.

Fabrication and procurement of certain components like high voltage support structure, corona guards, RF electrodes, dome shields, high voltage terminal dome, 150 KV–0–150 KV RF transformer, high voltage rectifier stacks, etc. have been extremely difficult because of inadequate industrial capability in our country in executing these types of complex components, requiring close tolerance and ultra-finish for withstanding high electric field stresses. However, with continued efforts and interactions, we have overcome those difficulties.

Most of the major components and sub-systems are now completed. Remaining few components of high voltage multiplier column are in an advance stage of fabrication at CDM. This power supply is a totally indigenous development except for the ultra-fast rectifiers, Litz wire and oscillator tubes which were

176 KV PIV Ultra-fast Rectifier Stack Assembly
of 3 MeV High Voltage Column

750 KV Resistive Voltage Divider Module

procured from outside. Using this technology we will be able to build DC power supplies of much higher voltage and power ratings.

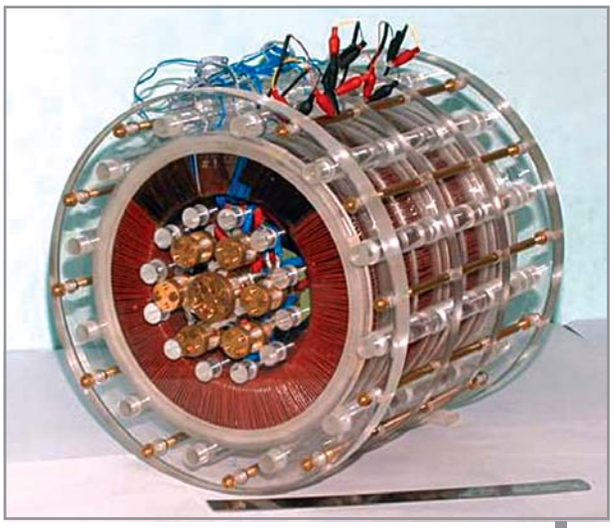
R.I. Bakhtsingh <rib@barc.gov.in>
Dr.K.V.Nagesh <kvnag@barc.gov.in>

Pulse Transformer Development for Linear Induction Accelerator

Pulse voltage step-up in the Linear Induction Accelerator (LIA) is done by using two pulse transformers: (i) 2.5KV/20KV, 20 μs, 250 J and (ii) 20KV/200KV, 5 μs, 200 J. These transformers operate in resonant mode at high power (20 MW and 80 MW respectively) to charge the capacitors at 100 Hz repetition rate.

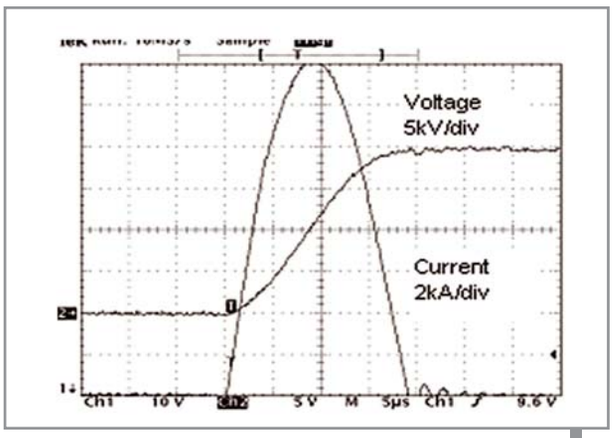
The 2.5KV/20KV pulse transformer has been designed to charge a 1.2 μF capacitor at 20 KV in 20 μs time by discharging 80 μF, 2.5 KV capacitor across the primary terminals. This transformer has been built and tested at the rated output for single pulse and at 2 to 3 pulses per second repetition rate. Unlike power transformers, the design is based on low-loss Metglas torroids to reduce core losses and achieve compact size. Pulse duration is given by $T = \Pi\sqrt{LC}$ where L and C are leakage inductance and effective capacitance respectively referred to primary side. Single-layer, concentric windings are made to reduce leakage inductance and improve coupling-coefficient (0.999). Six identical modules each of 2.5KV/20KV, 50 J ratings operate in parallel adding mode, to get desired low leakage inductance ($\approx$0.8μH), to distribute currents for reducing repulsive forces in the windings and to improve cooling. DC resetting of cores has been incorporated for repetitive operation. Energy transfer

efficiency is 89% and total weight is 33 kg. The photograph of the 2.5KV/20KV pulse transformer and the test results are shown below. Primary and secondary currents are 16 KA and 2 KA respectively. Short circuit impedance and winding resistance are 114 mΩ and 6 mΩ respectively.



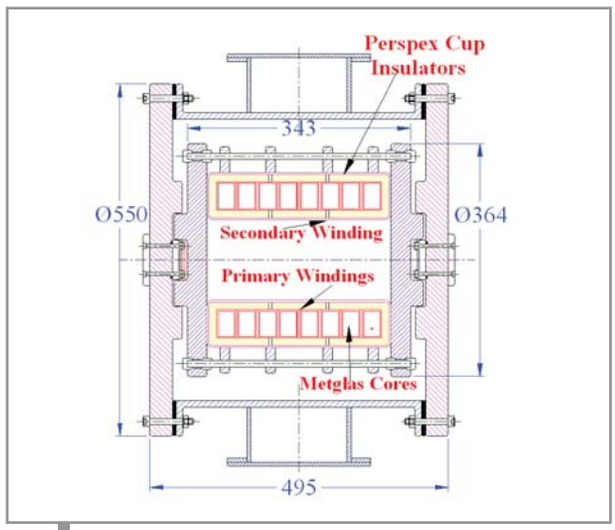
2.5KV/20KV, 20μs Pulse Transformer

The 20KV/200KV transformer has been designed to charge 10 nF capacitor at 200 KV in 5 μs time by discharging 1.2 μF, 20 KV capacitor across the primary winding. Design of this transformer is also based on Metglas torroids.



Test Results of 2.5KV/20KV Transformer
(Ip= 16.2 KA (Peak), VS = 20 KV, T= 19.5 μs)

Short-circuit impedance and primary winding resistances are 3 Ω and 2 mΩ respectively. Eight primary windings each of 35 turns are separately wound on individual cores and connected in parallel to reduce leakage inductance. Kapton tape will provide 20 KV insulation between cores and primary windings.



Cross Sectional View of 20KV/200KV,
5μs Pulse Transformer

Perspex cup-structures along with Mylar-sheets provide 200 KV insulation between primary and secondary windings. Electrical-stress between primary and secondary is 160 KV/cm in the transformer oil medium.

D.K. Sharma <ksharma@barc.gov.in>
Dr.K.V.Nagesh <kvnag@barc.gov.in>

Design and Fabrication of Breaker Control Modules for CERN

Breaker Control Modules for LHC super-conducting magnets

Control electronics is required to energize or de-energize the breakers, which in turn power the superconducting magnets. The control electronics also protect the super conducting magnets in case of faults. To energize or de-energize the magnet and to bypass the current, the stored energy is dumped in a resistor. The Breaker Control module consists of a cabinet containing the electrical and electronics circuits. This is used for powering and controlling the closing and opening mechanism of four identical 4.5 KA DC circuit breakers as well as for providing signals for supervision of the state of four associated breakers.

Breaker Controller

Four DC breakers are connected in parallel and provide 13KA to the super-conducting magnet coil. Control and Instrumentation Division (CnID) of BARC along with CERN have participated in the design, development, fabrication and testing. First eight BCM were fabricated at ECIL and after testing with actual breakers, the design was verified and approved. The total requirement of CERN (70 modules) were fabricated and delivered to CERN.

Quench Heater Power Supply (QHPS) for LHC Superconducting Magnet

The QHPS system is required to protect the superconducting magnets in case of quench (resistive transition of super-conductor) detection in the magnet coil, carrying current up to 13 KA. The protection system gives the trigger command to the Quench Heater Power Supply to power the quench heater strips of the magnet. This heater strip is installed on the outer layer along the magnet coil. By powering heater strips the energy is distributed evenly in entire magnet. The QHPS consists of six 4.7 mF/500 V capacitors which are connected in parallel and series mode to form 7.05 mF/1000 V capacitor bank. This capacitor bank is kept charged to 900 V and it is discharged through heater strips by triggering a pair of thyristors receiving on getting a trigger command from quench detection system. BARC has participated in the design and development, fabrication and testing of QHPS along with CERN. The pre-series productions were carried out at ECIL. After the approval of these units the requirement of 5500. of such power supplies will be delivered to CERN. This work was done for the Large Hadron Collider (LHC) under the DAE-CERN Collaboration.

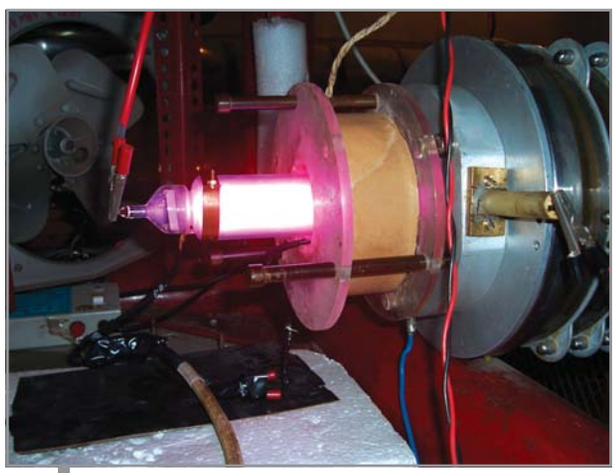
Electronics for Accelerator Based Systems

Presently, in the Purnima sub-critical facility in HPPD, the deuterium ions generated in the ion source are extracted and accelerated to 400 KeV and then allowed to impinge upon a Tritium target, located within a sub-critical core, to produce 14 MeV neutrons. Following electronics has been developed for this facility:

- 200 W @ 100 MHz CW RF power supply used in the ion source;
- High stability solenoid current supply and
- Pulsed 8 KV ion extraction voltage.

The 14 MeV sub-critical facility is being augmented by replacing the 400 KeV accelerating column by a 50 KeV and introducing an RFQ driven at 350 MHz to accelerate the deuterium ions to 400 KeV.

The RFQ will be powered by a 70 KeV tetrode-based power source. This RF power source has been designed and its development work is currently in progress. 100 W @ 350 MHz and 1.5 KW @ 350 MHz drivers have been developed for the 70 KW RF source.



Deuterium Plasma of RF Ion Source at Purnima

100 MHz 200 W RF Power Supply

800 A, 10 V Current Regulator for ECR Ion Source

Development of high power proton accelerator has been undertaken under the plan project "Physics Studies and Technology Development for ADS". High power DC and RF electronics is required for the 50 KeV ECR ion source, RFQ (3 MeV), DTL1 (10 MeV) and DTL 2 (20 MeV) to be used in this accelerator.

Besides this, various high power microwave components like power circulator, RF load, wave guides, directional couplers, E and H bends, elbows and T's, power couplers, etc. are needed to couple the 1 MW power to RFQ, DTL 1 & 2. Development of 800 amps @ 10 volts current regulator required in the ion source has been initiated.

High current and high stability (50 ppm) regulators (500A / 50V, 200A / 20V) have been supplied to energize the two bending magnets in FOTIA project. Recently, another current regulator (350A /35V) for the third bending magnet has been completed and delivered. Besides this, development work has been taken up for SMPS-based 6A / 60V and 50A / 70V current regulators for beam switching magnets of FOTIA.

350 MHz 100W Driver for Klystron

Design of a 70 kW, 350 Mhz High Power Amplifier (HPA) for 400 keV RFQ Accelerator, M.M. Pande, M K V Rao and V K Handu, **Indian Particle Accelerator Conference InPAC-2005 VECC,** Kolkatta, march 2005.

Conceptual Design of 1 MW CW 350 MHz Klystron based RF System for 3 MeV RFQ of ADSS, Manjiti Pande, B.V. Rama Rao., M.K.V. Rao, and V.K. Handu, **Indian Particle Accelerator Conference InPAC-2005 VECC,** Kolkatta, March 2005

Design of a high stability 600A, 10V current supply for ECR ion source, V. Perayya and Usha Karandikar, **Indian Particle Accelerator Conference InPAC-2005 VECC,** Kolkatta, March 2005

V K Handu **<dsctppd@barc.gov.in>**

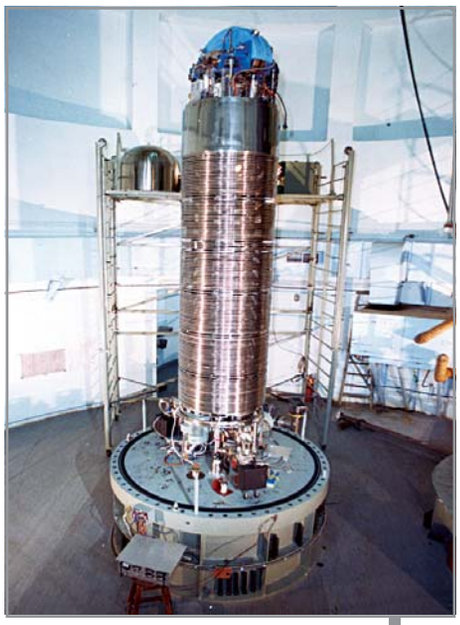
6 MV Folded Tandem Ion Accelerator

The indigenously built FOlded Tandem Ion Accelerator (FOTIA) has been set up at the Nuclear Physics Division, BARC. The accelerator is capable of delivering heavy ion beams up to A≈40 and beam energy up to 66 MeV, for ions with charge state of 10^{+}, at a maximum terminal voltage of 6 MV.

The FOTIA is an accelerator of its kind amongst a few in the world. Its construction involved development of state-of-the-art technologies of several important components like high

voltage generator, dipole magnets, SF_6 gas handling system, vacuum systems, magnetic and electrostatic lenses, computer control system and front line electronics, etc.

Initially, a gas mixture of N_2+CO_2 was used and a voltage of 3.4 MV was achieved on the high voltage terminal. Later on the accelerator tank was filled with SF_6 gas and the terminal could be raised to 5 MV. For increasing the terminal voltage to 6 MV further conditioning of the column section is needed which is being done. The high voltage is stabilized using a stabilization system developed in the lab. A 90°-magnet with 0.1% field homogeneity is used to analyse the beam.



High Voltage Column Section

The stability of the terminal voltage was measured using nuclear reaction $^{12}C(p,p)^{12}C$ and was found to be ± 2 kV. Charged particle beams (proton, lithium, carbon, oxygen, fluorine) from the FOTIA have been used both for nuclear cross section measurements as well as analytical work using RBS, ERDA and PIXE techniques.

The proton beams have also been extracted in air and used for radiation damage studies on live cells. A new hall has been constructed where five beam lines are being installed for research in basic and applied sciences in the field of nuclear physics, material science, atomic spectroscopy, radiation biology, etc.

90^0 - Analysing Magnet

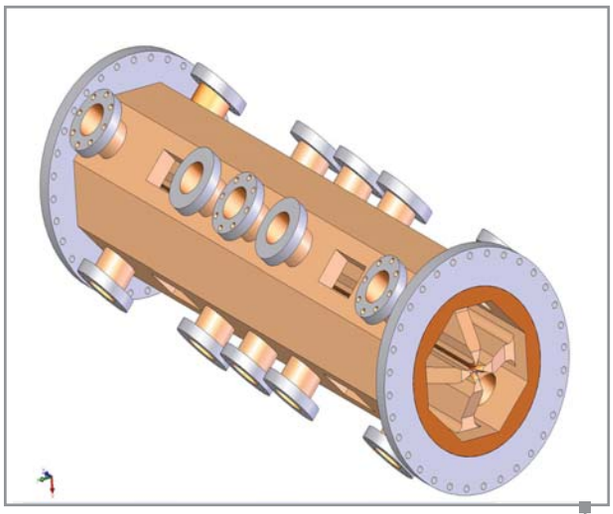
PIXE Setup

S. K. Gupta <**sgupta@barc.gov.in**>
P. Singh <**psingh@barc.gov.in**>

Accelerator R & D for ADS Programme

ADS project is the first step in pursuance of the ADS development roadmap of the BARC. A major facility, LEHIPA (**L**ow-**E**nergy **H**igh-**I**ntensity **P**roton **A**ccelerator) under it would set up 20 MeV, 30 mA cw proton linear accelerator. Proton beam is emitted at 50 keV from an ion source of Electron Cyclotron Resonance (ECR) type. This beam is accelerated to 3 MeV in a Radio Frequency Quadrupole (RFQ) accelerator and then up to 20 MeV through Drift-Tube Linac (DTL) structure.

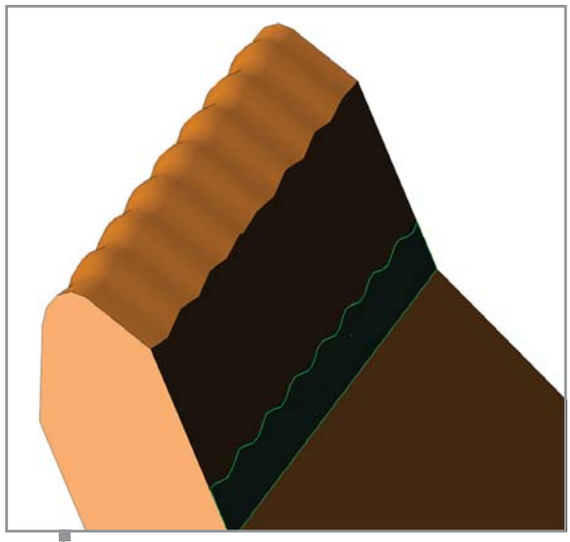
In this scheme, systems of ECR ion source are under fabrication and design of RFQ prototype is complete. This will be fabricated to accelerate deuteron beam up to 400 KeV when energised by 350 MHz RF power source based on tetrode tubes. 3 MeV RFQ sections will be fabricated on the basis of results from tests/ performance of the prototype. Preliminary designs of DTL have been made to initiate work on several of its systems like- RF power supplies, cooling water, building layout with appropriate shielding and the proton beam dump. Most these tasks involve working in new disciplines for the first time in the country.



400 KeV Prototype RFQ

The fabrication details and RF system for 1.05 m. long, 400 keV prototype RF included RF and thermal analysis of various features and selection of RF system equipments.

The RFQ assembly is to be fabricated from Oxygen-free (max. O_2 < 10 ppm) electronic grade copper by very precise machining yielding high internal surface finish and subsequent vacuum sealing by furnace brazing.



Modulated Vane Profile

The profile accuracy of about ±0.020 mm in each of 4 vanes is required for entire length of RFQ cavity. For this reason, several short models would be made and tested (cold tests) for validation of RF design calculations, machining errors and brazing cycle. Final tests will consist of energising with about 70 kW RF power (hot tests) and monitor stability of various operating parameters like detuning and local heat dissipation at ports and openings. When it becomes operational, 400 keV deuteron beam can be used to generate 14 MeV (D-T) neutrons for conducting reactor physics experiments with ADS sub-critical core. The facility layout for 20 MeV proton linac, would also house its three RF generators (each 1MW RF output klystron) and the 600-kW beam dump in basement at a depth of about 8 m below ground. The driver DC power to klystrons at 95 kV and 24 A would be obtained from special power supplies developed at the Institute for Plasma Research (IPR), Ahmedabad. Most (80%) of the RF power to RFQ and DTL would to be dissipated in the accelerator structure, which uses special cooling water system to maintain and control temperatures within ±0.1°C. Design and fabrication strategies for these technologically challenging systems for LEHIPA, constitute fundamental part of accelerator development which would be capable of driving a full-scale ADS.

P. K. Nema <pkn@barc.gov.in>
Dr. P. Singh <psingh@barc.gov.in>

2.2 RF INSTRUMENTATION

A superconducting linear accelerator (linac) is being installed in the Phase-2 of Medium Energy Heavy Ion (MEHIA) Project at TIFR as a BARC-TIFR joint facility. At the very beginning of this project, it was decided to develop the required RF and Control Electronics indigenously. The linac consists of a series of resonators mounted along the beam-line. These are independently phased RF systems. Stability of amplitude and phase of RF fields in the resonators of the linac is an extremely important requirement. In addition, a reference phase distribution system, which also takes care of the drift through the Pelletron (the DC accelerator installed in the first phase of the MEHIA project) is required to retain the synchronization of beam bunches with RF field in these resonators. The first phase of the linac comprising 13 superconducting resonators has been installed using the RF and control electronics developedindigeneously. The first beam run through the linac was taken up in September 2002. Since then beam has been successfully accelerated through this part of the linac on a number of occasions. Currently work on the second phase of the linac is in progress.

The RF and control electronics developed indigenously for the superconducting linear accelerator includes a number of RF systems like Resonator Controllers and support modules at different frequencies, RF Power Amplifiers, Dynamic Reference Phase Generation system etc. The hardware and software for the computer control of all these front-end RF systems has also been developed in-house. The indigenously designed and developed RF Control Modules, RF Amplifiers, CAMAC Modules and Control Software have not only made the system economical but also generated expertise which will be very useful for the up-keep of the system and helpful in meeting the future challenges in the ADSS program taken up by the Department. The activities in the area of RF electronics have led to very fruitful collaborations with national institutes like Inter-University Accelerator Centre (IUAC) (formerly known as Nuclear Science Centre), New Delhi and Bharat Electronics Limited, Bangalore. This work has also received international recognition. Australian National University (ANU), after a careful evaluation of the various options available to them, has used the RF control electronics developed at BARC for their linac. The RF Control system has been commissioned in the linac at ANU in May, 2005. The performance of the system has been found to be very good. In another collaborative program with CERN, Geneva, an RF system model has been developed for the linac2 at CERN.

■ RF and Control Electronics for the BARC-TIFR SuperConducting LINAC

The Overall RF System

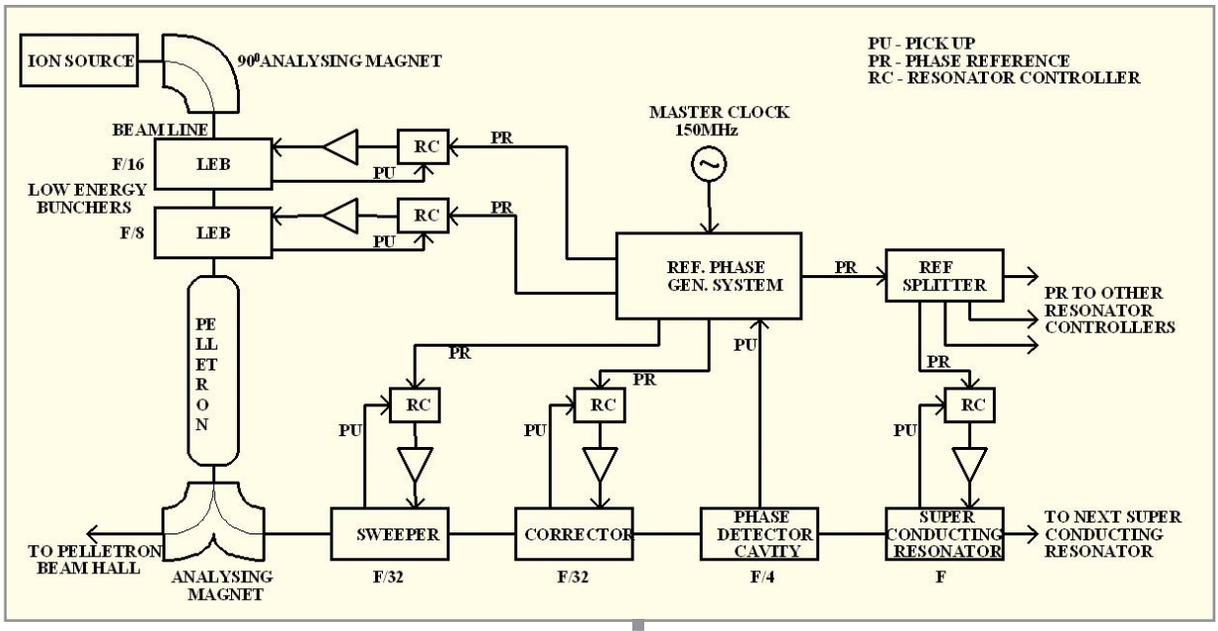
The low energy bunchers (which are normal conducting resonators) operating at 1/16 and 1/8 of the main linac frequency of 150 MHz, are used to bunch the DC beam available from the ion source into a range of 1-2 ns. Sweeper and Corrector resonators operating at 1/32 of the main linac frequency are used to remove the DC background in between the main beam pulses. The super buncher, which follows the phase detector, is a superconducting resonator. It improves the bunching to make the beam pulses suitable for injection into the superconducting resonators. The phase detector, with a resonance frequency of ¼ of the linac frequency, is a normal conducting resonator, which produces an RF signal in synchronism with the beam. This signal is utilized to generate suitable phase references for all the other RF systems in the linac. Beyond the super-buncher the linac is modular in nature. Each module consists of a cryostat housing four resonators.

The complete RF system for the Linac consists of:

1. RF electronics for the normal conducting resonators,
2. RF electronics for the superconducting resonators,
3. Overall Reference Phase Generation System.

RF Electronics for the Normal Conducting Resonators

Here we have four resonators: two Low-Energy Bunchers, Sweeper and Corrector. A generic design has been developed for all these resonators. It can be easily adapted for different frequencies by a change of non-critical components. The ease of parameter setting and wide dynamic range of amplitude control are features of this design. The controller employs a generator-driven architecture. The amplitude and phase are stabilized by controlling an attenuator and a phase shifter in the path of drive signal to the resonator. It has performed satisfactorily in the field. RF amplifiers for the normal-conducting resonators are commercially procured units.

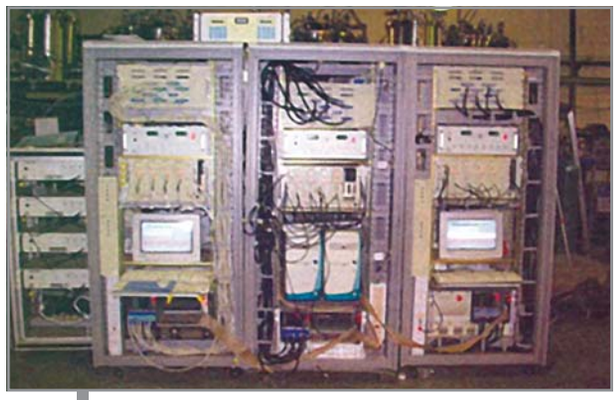


Schematic of LINAC

RF Electronics for the Superconducting Resonators

Due to narrow bandwidth of the superconducting resonators, stabilizing the RF field in these resonators poses a major challenge. Here, a self-excited-loop is formed by feeding the output of the resonator back to its input via a loop-phase shifter and a limiter. The self-excited-loop forms a convenient starting point for the setting-up of the field in the resonators. Subsequently this loop is amplitude and phase-locked to suitable references. This control strategy is very suitable for the BARC-TIFR resonators, which, at the operating field, have a small value for the product of energy content and the maximum deviation of their resonant frequency from the linac frequency. Control Electronics has been developed based on this strategy.

Resonator control electronics work under computer control via CAMAC hardware. All the low frequency analog and digital input and output signals of the RF control electronics are made compatible with corresponding signals from CAMAC modules which are also indigenously developed. It is possible to control the linac through the computer placed in the Control Room and observe the various control signals and status of resonators. The control system is web-based. A number of Java beans have been developed for usage on a web page which can be of use in other applications as well (web-based or otherwise).



The Instrumentation Racks at TIFR

At present the RF electronics required for 13 Superconducting Resonators have been installed at TIFR. Work on electronics required for the second phase of linac is in progress.

Overall Reference Phase Generation System

In order to retain the timing synchronization between the beam Pulses and the RF fields, the phases of RF fields in all the resonators are independently phase locked to a single master reference. To meet this requirement an overall Reference Phase Generation

System has been developed. This Reference Phase Generation System also corrects for the travel time variation of the beam bunches through the Pelletron, which occurs due to changes in the voltage distribution inside it. An RF signal in phase synchronism with the beam is extracted from the Phase Detector Resonator, which is a spiral resonator loaded with drift tubes. The phase of this RF signal is compared with the phase of the RF in the super-conducting resonators. Any error developed is removed via a feedback loop by correcting the reference phase of the low-energy bunchers. Feature of systematic and non-interactive setting of the phase references for all the RF systems in the linac has been incorporated in the design. This system has been installed in the linac and it has been possible to smoothly setup the RF system with it.

Gopal Joshi <gjos@barc.gov.in>

■ RF Control Electronics for IUAC, New Delhi

A Super-conducting linac is being installed at Inter University Accelerator Centre (IUAC), New Delhi. The resonators of IUAC linac are made of bulk Niobium with a center frequency of 97 MHz. With the success of BARC-TIFR linac, IUAC entrusted the task of developing RF Control Electronics of this linac to BARC. Redesign was carried out and the Control Electronics thus developed was extensively tested for suitability with IUAC resonators. With the success of this prototype, IUAC has placed an order for the RF Electronics for their complete linac on BARC. Forty eight RF Control Modules have already been supplied in two phases. Beam has been successfully accelerated through the first cryostat module using the electronics supplied by BARC.

Gopal Joshi <gjos@barc.gov.in>

■ RF Control Electronics for Australian National University (ANU) LINAC

The ANU linac has split-loop resonators with a center frequency of 150 MHz. RF-Control Electronics, consisting of 28 modules, has been supplied to ANU against their purchase order to BARC. The RF control system has been successfully integrated with the ANU linac in May
2005, when the first beam run was taken through the linac.

RF Control Electronics for ANU LINAC

Gopal Joshi <gjos@barc.gov.in>

■ RF System Model for CERN LINACs

As part of a collaborative program, a model for the complex RF system of the CERN Linac-2 accelerating tanks has been built using Matlab/Simulink. The behavior of an RF chain, especially during the critical transient part of cavity filling and beam loading, can be predicted avoiding long calculations and time-consuming experiments on the real system. The model shows good agreement with the actual observations and is being used for the identification of setting-up problems in the critical Tank2 of the CERN Linac-2. The model includes the accelerating cavity, a basic representation of the power amplifier, the feeding line and a complete description of the feedback loops. Because of the generic nature of most of the components used, it can be easily adapted for other similar systems. The above model will be very useful for analysis and design of RF systems of the High Intensity Proton Accelerator being developed under the project of technology demonstration for the ADSS.

(Gopal Joshi <gjos@barc.gov.in>

2.3 ELECTRON BEAM TECHNOLOGY

Electron Beam (EB) Technology has given a new direction and impetus to many industrial operations by opening up a new range of mechanical, chemical and metallurgical processing techniques. The versatility of this technique and the wide range of advantages that it offers, strongly favor the adoption of EB processing to meet the materials and manufacturing requirements in advanced technologies. Electron beam devices operate over a wide range of power levels: from a few kilowatts to a few hundreds

of kilowatts. The lower power ranges are used for industrial operations like welding, melting and non-thermal processing. The high power devices in the range of hundreds of kilowatts to megawatts are used in metallurgical applications.

BARC had realized the advantages of using Electron Beam processes in nuclear industry about four decades back when a decision was taken to indigenously develop the technology. Subsequently, the Electron Beam Technology Group was formed. With an increase in demand for various types of EB Machines, a number of welding, melting and evaporation units were built indigenously.

The research and developments efforts in EB technology thus initiated in BARC have been focused on developing a wide spectrum of EB machines ranging from low power coating systems to high power EB melting furnaces and strip type evaporation units for a variety of applications. The details of the various developmental projects both ongoing and completed are given below.

24 KW Electron Beam Welding Gun and Integrated Control & Monitoring of EB Welding Machine

A 24 KW capacity, Electron Beam Welding Gun, capable of producing a penetration of around 50 mm in stainless steel has been indigenously developed and commissioned at BARC. The unit operates at 80 KV using a tantalum formed cathode and will be used mainly for welding thick sections of stainless steel, copper and their alloys.

The 24 KW EBW Gun on Test Chamber

The 24 KW EBW Gun Mounted on Work Chamber

The soft console based main controller integrates the various EBW machine subsystems, viz. EB Gun, Vacuum System and Motion Controller. The vacuum control system has been implemented using in-house developed Programmable Controller.

The salient features of the system are

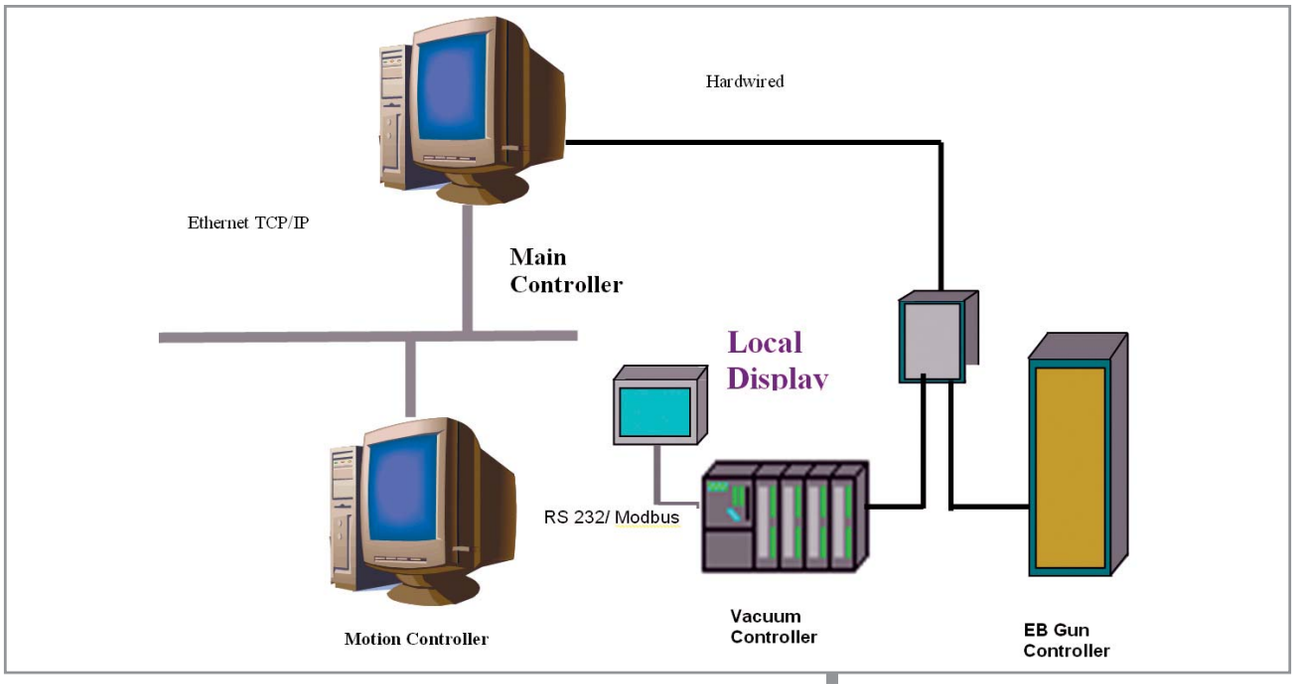
- Integrated Control
- Remote Defining, Editing & Downloading of G-code through Ethernet TCP/IP Interface
- On-line Monitoring of weld path
- Graphical Operator Interface
- Event logging
- On-line diagnostics and Fault Monitoring

The equipment has been jointly developed by L&PT Division, Center for Design and Manufacture and Reactor Control Division.

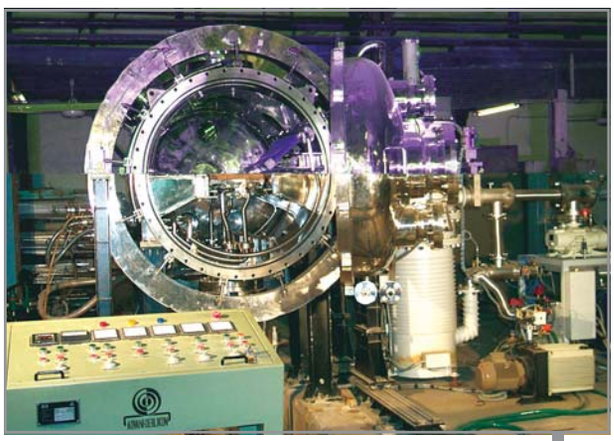
300 KW Electron Beam Facility

A 300 KW Electron beam facility indigenously developed, has been set up at BARC.

This unit consists of a large stainless steel work chamber that can house high power cylindrical or transverse electron guns and/or water-cooled crucibles with suitable heat shields. This facility is also provided with a pair of magnetic coils placed in Helmholtz's configuration for 270° beam deflection. This unit can handle power densities in the range of 10^4 to 10^6 watts/cm^2 and can be used as a test set up for high power electron guns.



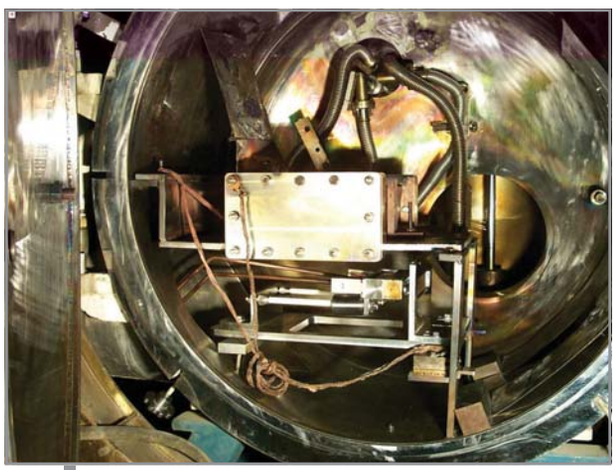
Integrated Control System for EB Welding Machine



300 KW Electron Beam Facility

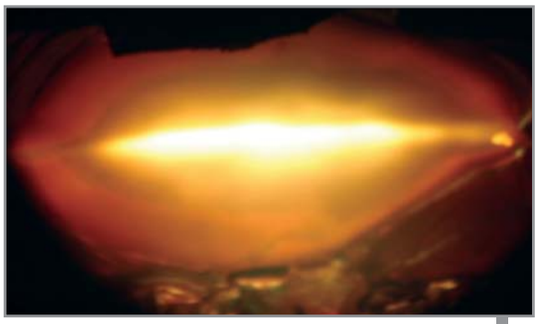
100 KW EB Gun Testing Facility

A high power electron beam test bench is a set-up to test and characterize high power electron beam guns. A 60 KV, 100 KW strip electron beam gun has been tested and characterized with this set-up. The unit has a non-magnetic, water-cooled, 1 m. diameter cylindrical vacuum chamber. Two electromagnets of 1.4 m. diameter are positioned in Helmholtz's configuration for beam bending. A water-cooled copper crucible is used for storing the charge. A power source rated for 60 KV, 200 KW is used for energizing the gun. A 60 KV, 100 KW strip beam gun with unique properties like very low beam losses, high voltage stability and capable of long term operation has been tested with this set-up. Studies on the beam shape both with AC and DC filament heating currents, measurement of beam power density and anode losses are carried out. All the components of the test bench are indigenously developed.



100 KW EB Gun Test Bench

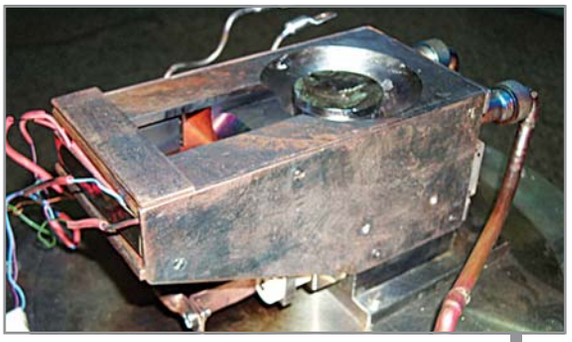
60 KV HVDC Power Source



60 KV, 60 KW Electron Beam on Copper
(Photo taken with Neutral Density Filters)

10 KW Electron Beam Evaporation Gun

A 10 KW transverse electron gun with static crucible has been developed in Laser & Plasma Technology Division with the primary objective of an indigenous high rate, electron beam evaporation system for development of specialized coatings. This unit which is designed for 10 KV operation has been assembled inside a test set-up and operated up to 10 KW power level.



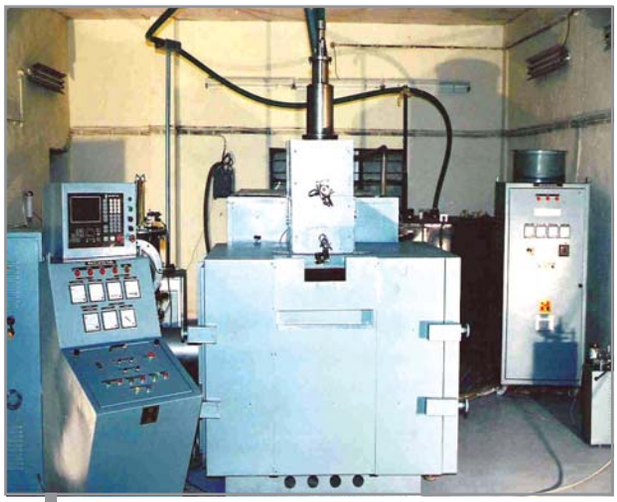
Gun-Crucible Assembly

Various coating trials of aluminum, copper, niobium and titanium have been carried out using this system. Coating thickness of 10 μm can be achieved after operation for 90 minutes. Titanium coatings of 8 μm (approx) thickness were successfully deposited on copper substrates at high vacuum (10^{-6} Torr) for the preparation of neutron targets for the ADS program.

10 KW, 270° Electron Beam Evaporation System

Demonstration Unit for Electron Beam Welding

The indigenously built in-house EB Welding machine which was in operation in BARC for the last twenty-five years has been leased out to M/s Siddhi Engineering Co., Navi Mumbai under an

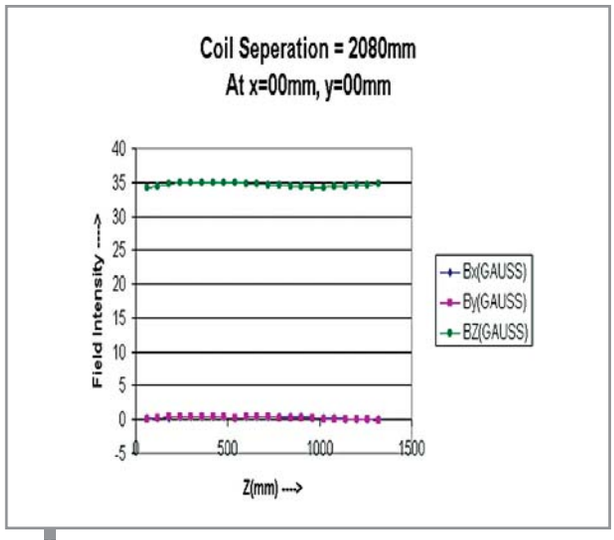


4 KW EBW Machine Commissioned at Navi Mumbai

MoU signed between BARC and the party for the exploitation of electron beam welding technology in the Indian industry. This 4 KW welding machine has since been commissioned and operated at the rated power. Several welds on AISI304SS tubes and a few automobile gear parts have been carried out successfully. The machine has been formally handed over to the party.

Large Volume Electro-Magnet

A large volume Electromagnet (Diameter ~ 4 mtrs) has been installed in Laser and Plasma Technology Division of BARC. The electromagnet was manufactured in Mumbai in a local transformer company with less than half the quoted price of an imported magnet. The electromagnet produces a uniform magnetic field (up-to 60 Gauss) in a cylindrical volume of diameter ~ 1 m and length ~ 1m with a non-uniformity less than 5%. These types of large electromagnets are useful in applications like high power strip coating plants, bio-exposure systems, EMC testing of instruments/equipment etc.



Magnetic Field along Central Axis Starting from Center of One Coil

Large Volume Electromagnet for Bending of Strip Electron Beam

3. ELECTRONICS AND SYSTEMS FOR BASIC SCIENCES

INTRODUCTION

Research in basic Sciences has always spurred the growth of instrumentation demanding more and more advanced technology. In turn, the intelligence and sophistication of instruments have been of tremendous help for the researchers. A number of advanced instruments using state-of-the-art technology have been developed for use in small laboratory-based experiments to accelerator-based big experiments for research in basic sciences under various DAE programs. The indigenous development of instruments described through following sections has also led to the development of standard instruments and core technologies.

3.1 MASS SPECTROMETERS

Mass Spectrometry is a crucial analytical tool for many DAE programs. High sensitivity isotopic mass spectrometry plays a key role in isotopic ratio measurements in samples of hydrogen, lithium, boron, uranium, plutonium etc. Since monitoring of deuterium, lithium-6 and uranium-235 in various enrichment processes as well as determining the overall tritium and plutonium produced in nuclear reactors, are extremely important tasks for DAE, BARC, since its inception in 1954, took up the development of technologies towards the underlying instrumentation programme in a major way.

The multidisciplinary mass spectrometry activity requires inputs from several fields. BARC has developed expertise in areas like HV/UHV technology, precision mechanical engineering and fabrication, magnet technology, ion optics, sensitive and stable analog and digital electronics, data systems etc. Over the past three and a half decades BARC has developed several mass spectrometers suitable for needs of a number of programs in DAE.

These include:

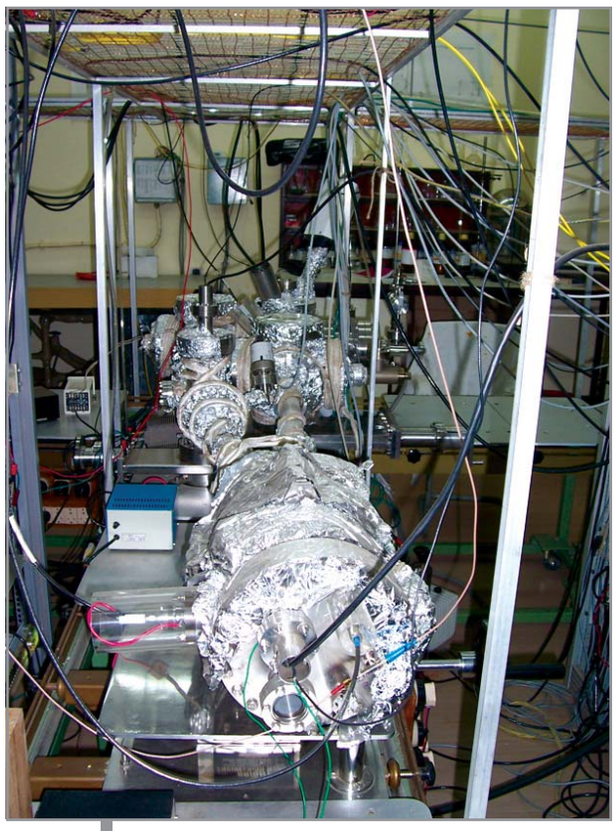
1) Isotopic mass spectrometers for isotopic ratio measurements for hydrogen, lithium, boron, nitrogen, potassium, rubidium/ strontium, uranium and plutonium.
2) General purpose gas source based mass spectrometers for inorganic analysis, organic analysis and for gas content in certain nuclear materials.
3) Inductively coupled plasma source mass spectrometer for elemental analysis.
4) Quadruple mass spectrometers.
5) Double focusing mass spectrometer with a resolving power of about 6000.

Heavy Water Board (HWB) has recently commissioned BARC to build three mass spectrometers for use in their programme. These are: TIMS mass spectrometer with a twin ion source, for solid and gaseous samples, for analyzing Boron 10 / 11 in the form of sodium metaborate as well as Oxygen 16 / 18 in the form of carbon dioxide gas respectively; QMS mass spectrometer for Oxygen 16 / 18 in the form of Carbon dioxide gas; and ICP mass spectrometer to analyze Boron 10 / 11 as well as trace impurities present in Boric Acid, Boron Metal and Boron Carbide. MS&ESS has taken up this development and these instruments are in an advanced stage of fabrication and assembly.

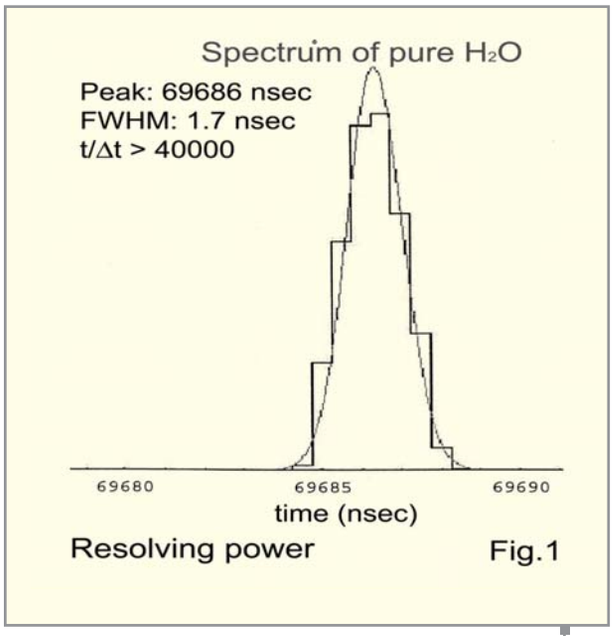
■ High Resolution Reflectron Time-of-Flight Mass Spectrometer

The spectrometer consists of a broad high current (mA) ion source that works on the principal of magnetron wherein the electrons are trapped in a specific volume . The ions in the plasma within the volume are then extracted by applying opposite potentials and then channeled into the special ion optics to accelerate them perpendicularly into the drift space and subsequently to the reflectron through a symmetric lens system. This four-electrode quadrant ion optics is a new design that resulted in a large dynamic range and higher resolving power.

(I) *The Ion Optics* – The ionization volume is located at the center of the optics and is confined to within 2 mm^3, from which the ions are accelerated and by dint of this confinement the optics essentially



Reflectron Time-of-Flight
Mass Spectrometer



The Spectrum Recorded for H_2O Showing the Resolving Power of the Instrument

works as the dummy ion source eventually leading to the spectrometer. That is independent of any particular ionization method. Thus, different techniques of ion production e.g. electron impact, photo ionization, matrix desorption, electro spray, ICP etc. can be suitably interfaced. Because of the gridless design, there are no transmission losses, leading to enhancement of both sensitivity and dynamic range. (II) *Reflectron* – This takes care of the KE differences of isomass ions and hence enables a higher resolution of the spectrometer. (III) *Dual mode of operation* – The spectrometer can be operated both in linear as well as in reflectron mode of operation, typically demanded for the studies of large biomolecules. (IV) *IT-TOF mode* – The machine also has the provision of coupling a quadrupole ion trap just by replacing the ion optics.

Dr. A. Bhowmick <ashokb@barc.gov.in>
Dr. S.C. Gadkari <gadkari@barc.gov.in>

Electrostatic Ion Trap Mass Spectrometer

A new type of Ion trap has been designed which traps ions using purely electrostatic fields. The ion trap works like an optical resonator. Two electrostatic ion mirrors are placed collinearly and ions are injected into the trap. The oscillation frequency of the

Electrostatic Ion Trap Mass Spectrometer

trapped ions is measured using an image charge detection setup. The Fourier Transform operation on the oscillatory signal from the image charge detector is then analyzed to reveal the information of the ionic masses. It can be seen that the larger the number of oscillations analyzed, the higher will be mass resolution.

At present, various tests are being carried out to check the performance of individual subsystems. Ar^+ ions at 4.2 keV produced from an electron-impact ion source were extracted, focused and transported to the ion trap as well-defined ion beam. An electrostatic beam chopper was used to pulse the dc ion beam and ion bunches so produced could be trapped with the ion trap. Initial tests have shown a lifetime of about 100 ms at a background pressure of $\sim 10^{-9}$ Torr that corresponds to about 36,000 oscillations of the ion bunch. The ultimate mass resolution is expected to be in the range from 5 x 10^4 to 10^5 and the masses up to 10^6 amu could be measured on the mass spectrometer.

Dr. K.G. Bhushan <bhushan@barc.gov.in>
Dr. S.C. Gadkari <gadkari@barc.gov.in>

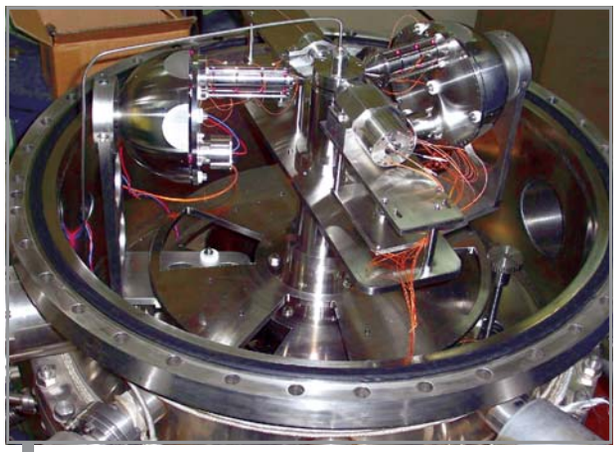
■ High Resolution Electron Spectrometer

Electron–molecule collision reactions form the primary basis for a stable plasma state, which is the core process in many natural phenomena such as fusion, planetary atmospheres, inter-stellar physics and magneto-hydrodynamic reactions. Understanding the physical process of electron – molecule collisions thus enhances the knowledge of the above-mentioned phenomena.

An electron–molecule collision spectrometer has been setup, basically to measure differential cross sections of various molecules. The spectrometer consists of an electron gun, two identical hemispherical energy analyzers, a faraday cup and a gas inlet system. The electron gun fitted with thoria-coated tungsten cartridge filament is used to produce a nearly mono-energetic beam of electrons over a broad energy range (10–1500 eV) and currents up to 10 μA. The hemispherical analyzers coupled with 5-element electrostatic zoom lenses are mounted on rotary turntables and image the scattering volume. The outgoing electrons arising out of a scattering reaction are analyzed, in both energy and momenta.

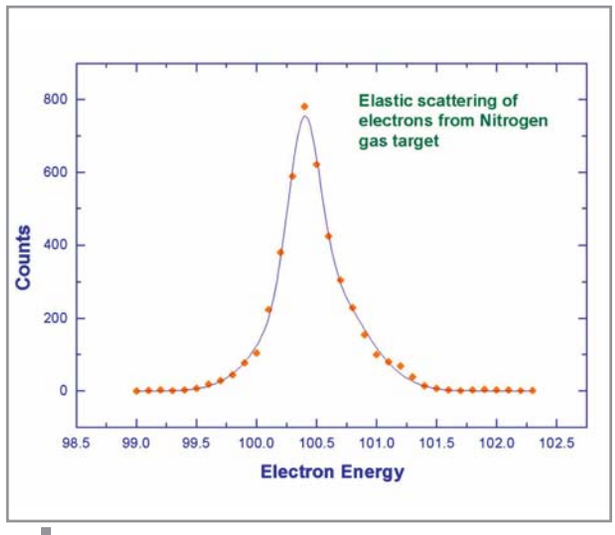
A channeltron detector is used to detect the analyzed electrons. The faraday cup continuously monitors the incident beam current.

A fine control leak valve connected to the gas-inlet system is used to let in the test gas at the scattering centre. The entire spectrometer is kept in an ultrahigh vacuum chamber, pumped by a 500 l/s turbo molecular pump giving a residual pressure of about 5 x 10^{-8} Torr.



High Resolution Electron-Optic Spectrometer

The detection electronics is based on fast pre-amplifiers coupled to the channeltron detectors. The pulses from the channeltron detector are amplified and are fed to a constant fraction discriminator. The noise pulses are discriminated and the actual counts are counted by a scalar



Measured Data for Elastic Scattering of Low Energy Electrons from N_2 Molecules at Room Temperature. Note the FWHM of ~ 0.5 eV

and also given to a PC-based counter card. Similar PC- based interface cards are employed to scan the voltages to the analyzer and to rotate the analyzers from outside by using stepper motor drive units. Finally, the accumulated data is displayed online as a spectrum containing the energy of the incident electrons and number of counts accumulated from the scattering reaction.

Dr. K.G.Bhushan <bhushan@barc.gov.in>
Dr. S.C.Gadkari <gadkari@barc.gov.in>

Mass Spectrometers for Heavy Water Analysis

More than twelve double collector, isotopic ratio mass spectrometers for D/H analysis have been fabricated and installed so far at various Heavy Water Plants and in various Divisions of BARC. In fact, very recently a new D/H mass spectrometer has been supplied to Heavy Water Division where it is being used for testing of distillation column used for heavy water up-gradation, performance testing of catalyst used for hydrogen water exchange, and other R & D activities.

D/H Mass Spectrometer

This type of mass spectrometer presently gives a precision of about 2 ppm at natural level (153 ppm) in the isotopic ratio measurement of mass3 and mass2 dispersed ion beams. To improve this precision figure, development of a new and automated sample inlet system has been undertaken.

Development of New Software for TPPED Make D/H Mass Spectromters, R.B.Igole, Ramkumar Nair, R.G.Ochani and V.K.Handu, **10th ISMAS National Institute of Oceanography,** Goa. January 27-31, 2003.

R. B. Ingole <ingolerb@barc.gov.in>

Process Gas Mass Spectrometers (PGMS)

Process Gas magnetic sector, multi-collector mass spectrometers are used at RMP, to measure the isotopic abundance of masses 329, 330 and 333 (isotopes of UF_5 corresponding to Uranium 234, 235 and 238) in enriched or depleted UF_6 samples and also to measure precisely the isotopic ratios of mass 330 and mass 333. Four such mass spectrometers PGMS 1, 2, 3 & 4 have been supplied to RMP during the last few years (PGMS 4 has been supplied and installed recently) and are being used very extensively since then.

Process Gas Mass Spectrometer

Magnetic Field Simulation using SIMON- Effect of pole height on the position of Equivalent Ideal Boundary, R.K.Bhattia, V.V.K.Rama Rao., N.Padma and A.D.Kulkarni, **10th ISMAS National Institute of Oceanography,** Goa. January 27-31, 2003

V. Natraju <vogirala@barc.gov.in>

Thermal Ionization Mass Spectrometers (TIMS)

TIMS type magnetic sector multi-collector mass spectrometers are used to determine the isotopic abundances of Li, B, U and Pu isotopes in solid samples. Two such mass spectrometers were delivered earlier to the Chemical Engineering Division for Li and B isotopic analysis while three similar instruments, but with different geometry, have been delivered to RMP, for U isotopic analysis and to AFFF, Tarapur, and KARP, Kalpakkam for U and Pu isotopic analysis.

Design and fabrication of an advanced version of TIMS mass spectrometer for U and Pu analysis have been undertaken. This instrument is in an advanced stage of assembly. Improvements

carried out are: new ion source with higher ion yield, einzel lenses for better focusing, 10 kV ion accelerating voltage (compared to 5 kV in the earlier instruments), and improved electronics, control and data acquisition.

Electron Impact Ion Source Accessory for Thermal Ionization Mass Spectrometer, S.N.Bindal, K.V.Kurup, K.A. Sayed, N.V.Rao and V.V.K.Rama Rao, **10th ISMAS National Institute of Oceanography,** Goa. January 27-31, 2003.

S. N. Bindal <sbindal@barc.gov.in>

■ Quadrupole Mass Spectrometers (QMS)

Development of QMS has been undertaken as an R & D effort because of its applications in faster isotopic and elemental analysis. The source of ions can be electron bombardment type ion source for gas sample analysis or an inductively coupled plasma ion source for trace element analysis. Over the last few months, quadrupole mass spectrometer, which can analyze masses up to 300 amu, has been successfully completed. This has been verified by analyzing standard sample like Per Fluoro Tributyle Amine (PFTBA). Samples like CF2HC (used for C13 enrichment); O16 and O18 isotopes in CO2 gas to measure the abundance of O18 have also been successfully analyzed for various applications.

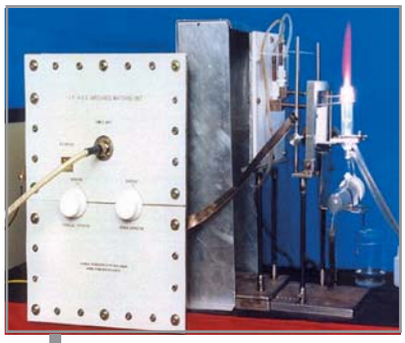
The QMS developed here is now totally indigenous. The quadrupole mass analyser and its RF and DC electronics, the vacuum system, and electronics for ion detection, control and data acquisition are all developed in-house.

Development of Quadrupole Mass Analyser with Pre and Post-filter Segments, V. Nataraju and V. V. K. RamaRao, **10th ISMAS National Institute of Oceanography, Goa.** January 27-31, 2003.

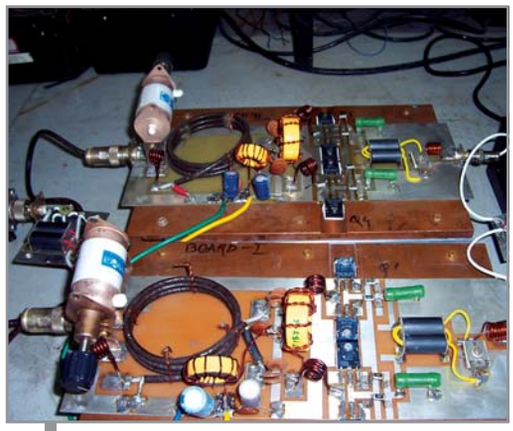
V. Natraju <vogirala@barc.gov.in>

■ Inductively Coupled Plasma Ion Source Mass Spectrometer (ICPMS)

Development of ICPMS has also been undertaken as an R&D effort because of its application in trace element analysis (sensitivity as low as sub-ppb level) and, more recently, in isotopic ratio measurements. First of the prototype ICPMS has been completed with most of the sub-systems developed in-house. These include: differential vacuum system, 2.5 kW / 27.12 MHz RF generator, plasma torch, impedance matching electronics, skimmer and sampler cones, ion optics, Quadrupole Mass Analyser (QMA), RF and DC supplies for QMA, ion detection electronics, data acquisition in continuous and pulse counting modes, and electronics for the control of various sub-systems in the mass spectrometer. This instrument gives a sensitivity of better than 10 ppb for most of the elements.



Torch for ICP-AES



Solid State RF Power Supply
(1000W 27.12MHz each) for ICPMS

Inductively Coupled Plasma Mass Spectrometer

Indigenous Development of ICP-MS, V.Nataraju, **10th ISMAS Workshop on Mass Spectrometry. Institute of Physics, Bhubaneswar,** Feb 25 to March 1, 2002.

V. Natraju <vogirala@barc.gov.in>

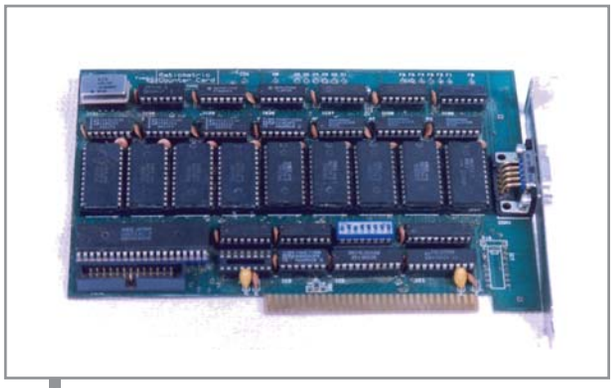
■ Electronics for Mass Spectrometers

High stability electronics and high-resolution data acquisition and control electronics for all the mass spectrometers described above have been developed in-house. These include:

- Sputter ion pump control electronics (SMPS based up to 70 l/ sec, and Leakage Reactance Transformer based up to 500 l/sec);
- Pirani and ionization gauge controller for measurement of vacuum from atmosphere to 10^{-9} Torr;
- High stability regulated ion source electronics for generation of ions;
- High stability 5-8 kV / 10 mA DC voltage sources for ion acceleration;
- High stability magnet current regulators, up to 200 amps, of better than 10 ppm stability;
- PC / Microcontroller based ion source potential controls;
- Ion current amplifiers to measure sub-picoamp currents;
- PC based high resolution data acquisition and control electronics;
- RF generator (2.5 kW, 27.12 MHz) for ICPMS;

Sputter Ion Pump Control Unit

- RF and DC supplies for quadrupole mass spectrometers;
- Pulse counting based data acquisition electronics;
- FPGA based 100 MHz, 12-bit resolution PCI based data acquisition and control card with multi-channel scalar facility.
- Auto tuning in Mass Spectrometer.



Frequency Measurement Card

Electron Impact Ion Source Accessory for Thermal Ionization Mass Spectrometer, S.N.Bindal, K.V.Kurup, K.A. Sayed, N.V.Rao and V.V.K.Rama Rao, **10th ISMAS National Institute of Oceanography, Goa**. January 27-31, 2003.

Magnetic Sector Isotopic Ratio Mass Spectrometers- Improvements in Electronics and Software, M.M.Gulhane, R.Datta, T.K.Saha, C.K.Nazare, K.Joshi, V.B.Reddy and V.K.Handu, **10th ISMAS National Institute of Oceanography, Goa**. January 27-31, 2003.

Auto-tunning of Mass Spectrometer Ion Beam, R.B.Ingole, M.M.Gulane, Kuldeep Joshi, Rabi Datta. T.K.saha, C.K.Nazare, V.K. Handu and V.C.Sahani, **10th ISMAS National Institute of Oceanography, Goa**. January 27-31, 2003.

T. K. Saha **<tksaha@barc.gov.in>**

3.2 CAMAC INSTRUMENTATION

CAMAC is a modular data handling system that has been in use at nuclear physics research laboratories for more than three decades. In an endeavor to support the research activity, BARC sustained a very active program to develop new higher density CAMAC modules and data acquisition systems. The development was initiated in 1985 during the VII plan and it gained momentum in the VIII and IX plan. During this period, CAMAC crates, crate controllers and a large number of CAMAC modules were developed incorporating latest available technological changes to meet the requirement of

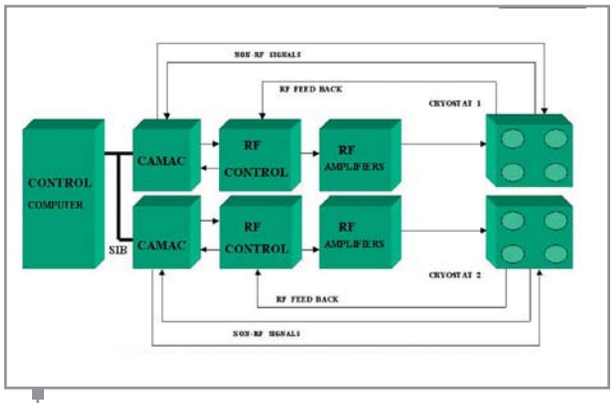
FOTIA Control System

laboratory and accelerator based research programs and other control systems. These include analog and digital input/output modules, scalars, stepper motor controller, communication modules and multifunction module. The analog process modules include 12 bit 16 channel ADC and 12 bit 8 channel DAC modules. The nuclear data acquisition modules vary in the channel density and type of input signal. Mainly they are Analog to Digital Converter (ADC), Charge to Digital Converter (CDC) and Time to Digital Converter (TDC). These have been installed at various laboratories of DAE. The major projects are Advanced Multi-Parameter system for nuclear experiments, control systems for FOTIA, LINAC and Industrial Accelerator at BRIT & instrumentation for GRACE project.

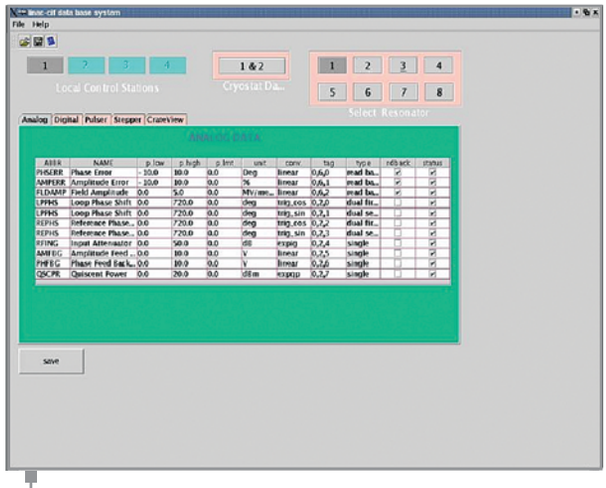
Instrumentation for GRACE

■ LINAC Control System

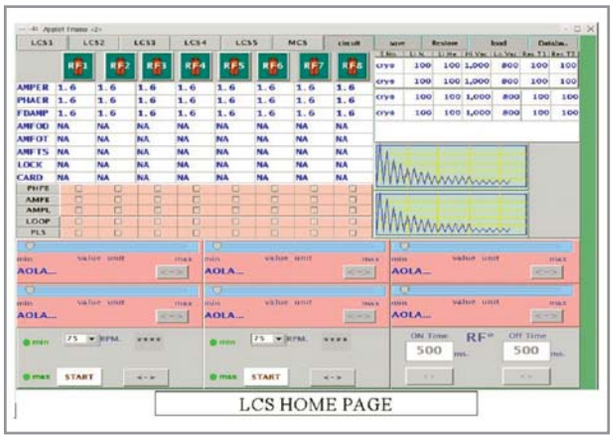
The LINAC control system has been developed as a Distributed Control System (DCS). Each node of the DCS is referred to as a Local Control Station (LCS). One LCS controls two cryostat modules. The Local Control Stations are connected over a LAN to the Main Control Station (MCS). The MCS has two PCs, which are kept, in the Main Control Room. The Schematic for each of the local control stations is given in figure below, showing the Control



The Local Control Station



Configuration Panel of Configuring Various Signals
Coming to the CAMAC



Computer which is a PC, the Resonator Controllers and RF Power Amplifiers with the CAMAC front-end.

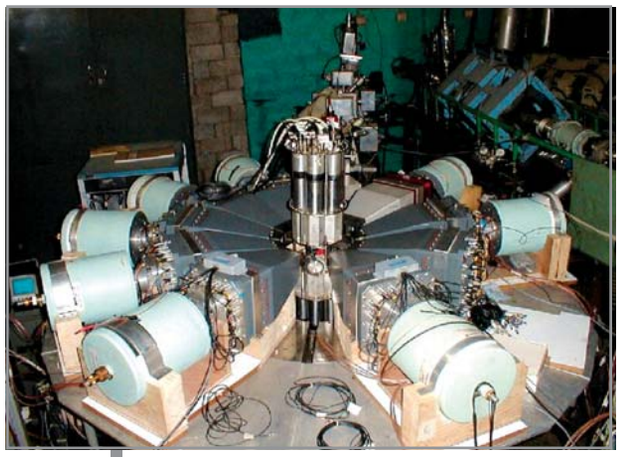
The CAMAC system consists of CAMAC crates, functional units like ADC, DAC, digital I/O units, stepper motor controllers etc. The CAMAC crate controllers are connected to the PC via the SIB (System Interface Bus). Each of the LCS has two crates and about twenty modules to handle about 120 RF-related parameters. The in-house developed CAMAC modules include 16 Channel Scanning ADC (12 bit resolution), 8 channel DAC (12 bit resolution), 48 bit digital I/O card and CC8 CAMAC crate controller cards. The data way units supplied along with the crates are useful for troubleshooting. A CAMAC crate with a number of functional units serves one cryostat (module) containing four RF resonators. The RF systems are connected to the CAMAC modules via junction boxes. Linux has been chosen as the Operating System for this Control System. The System has been designed as web-based system. Java has been chosen as the language platform since a number of vendors are supporting Integrated Development Environment for Java under Linux. The Linux driver for the CAMAC unit has been developed to access various CAMAC units.

Control System for BARC-TIFR Super conducting LINAC Booster, Gopal Joshi, C.I. Sujo, Sandeep Bharade, M.Meshram, K.jha, P.D.Motivala, Anita Behere, T.S.Ananthkrishnan, M.D.Ghodgaonkar, S.K.Kataria, S.K.Singh, J.Karande , **BARC News letter** No.230, March 2003.

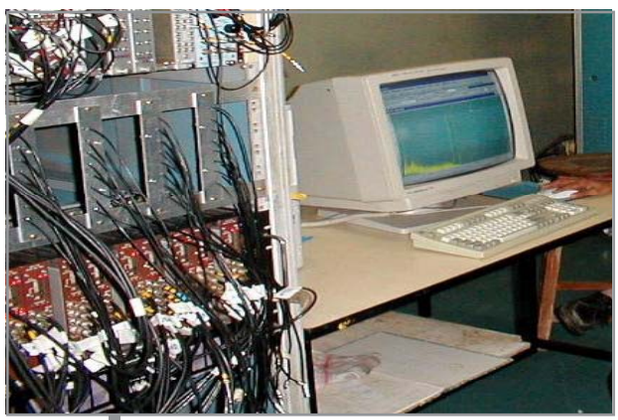
T.S. Ananthakrishnan <anant@barc.gov.in>

■ Advanced Multi-Parameter System (AMPS)

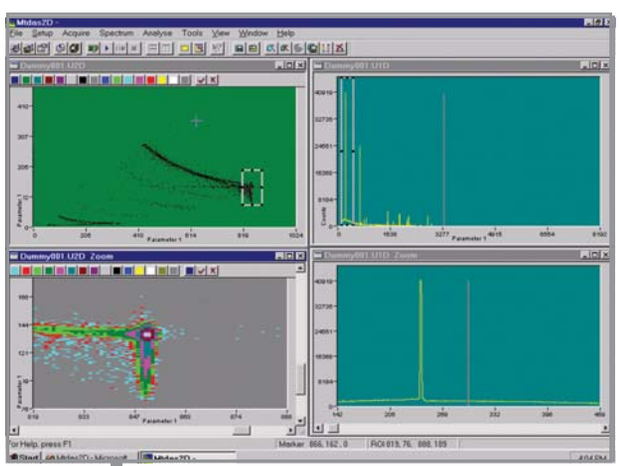
AMPS is a CAMAC-based multi-parameter data acquisition system with PC as the host. This system caters to simple laboratory



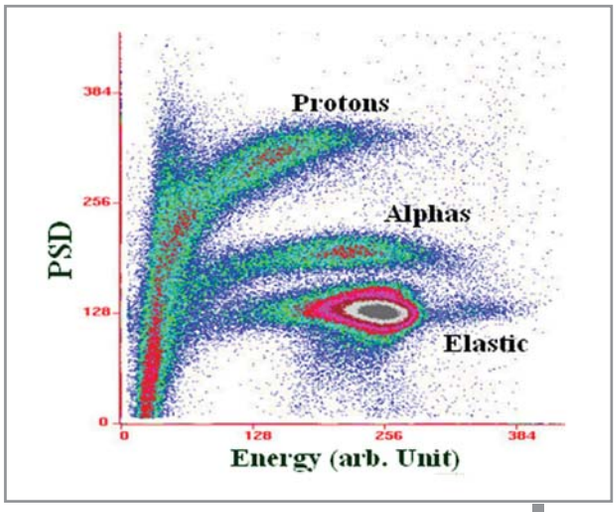
INGA Experimental Setup



AMPS in INGA Experiment



AMPS Software



2D Spectrum Acquired Using E/ΔE Detectors

applications and also online accelerator-based experiments. The CAMAC crate controller has been designed around Transputer to meet the high data throughput of the complex accelerator-based experiments. The PCI bus-based interface card under host control drives the crate controller. More than twenty-five systems have been installed at various labs of DAE such as BARC, TIFR, SINP, VECC, IOP, IIT, IUC and others. In a two-crate configuration, a throughput of 450 Kbytes/sec has been obtained.

The application software runs on the Personal Computer under the popular operating system Windows98 upwards. AMPS serves as an integrated data acquisition, analysis and display tool. Data analysis includes ROI selection, gate specification, peak find (Mariscoti search algorithm), Peak fit with reanalysis (Gaussin Peak fit) area calculator, and Energy Calibration (up to fourth order).

It provides rich display options including 1D / 2D Spectra, Rectangular ROI with projecting along X/Y axis, Rectangular / Banana Gates defining with easy editing, movement, storage and projection facility, user configurable color scale with 16 color palette for channel count display, overlapping of multiple spectrums in a single window with relative shifting to aid visual inspection and user configurable color scale with 16 color palette for channel count display. Its user-friendly setup/configuration options allow logical grouping of setup items in hierarchical property pages, provide simple define / edit / load / save setup options and perform automatic setup integrity and consistency checks and correction of interrelated setup items and error corrections. It also allows users to define pseudo parameters and includes built-in support for commonly used expression. In addition, AMPS also incorporates feature that enables user to add customized pseudo parameters computation in the form of Dynamic Link Library (DLL).

M. P. Diwakar <netsoft@barc.gov.in>

CAMAC Controller Nuclear Data Acquisition Modules

The nuclear data acquisition modules vary in the channel density and type of input signal. A few described below are the latest development using FPGAs and indigenous hybrids developed in collaboration with BEL, Bangalore.

CAMAC Crate Controller (CC2000) with PCI Interface

CC 2000 with PCI interface is specially designed as an intelligent controller for multi-parameter data acquisition systems.

The on board INMOS Transputer T225 operating at 25 MHz provides the desired concurrent data acquisition and transfer to the PC through the high speed Transputer Link to PCI interface. All the associated glue logic including the CAMAC interface is realized using CPLDs.

CC 2000 with PCI Interface

CC2000 with PCI Interface

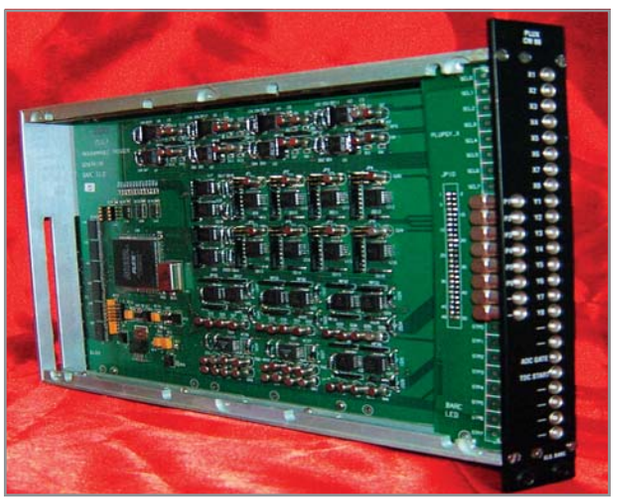
CAMAC Multi-Crate Synchronisation Module, CM90

In a multi-parameter system it is necessary that all ADCs, TDCs, QDCs and other CAMAC units be cleared simultaneously, for event-to-event synchronization. In a two-crate system, synchronization is achieved through CM90. One CM90 module is installed in each crate. One of the modules is designated as master and generates Master Clear as well Master gate. As different ADCs require ECL, NIM or TTL signals for GATE and CLEAR, all such signals are made available in CM 90 through on board jumper settings.

Programmable Logic Unit, CM95

In high-energy physics experiments with large number of detectors, a number of different types of NIM and CAMAC modules and a lot of interconnecting cables are required in order to generate the master trigger.

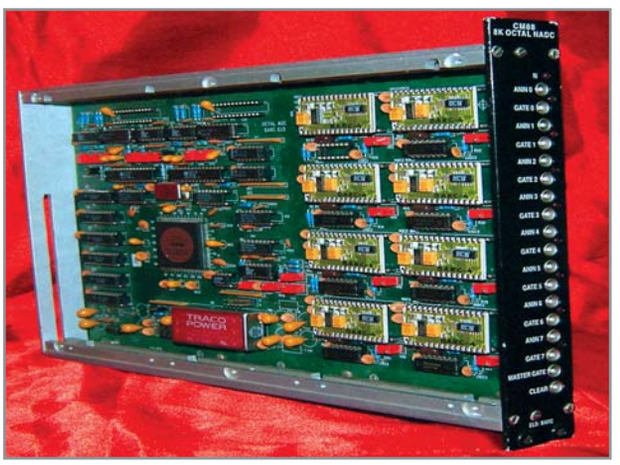
The Programmable Logic Unit has been developed using FPGAs to replace three to four of these modules. It is a Multi-function unit with coincidence, programmable delay, scalars and multiplicity logic implemented in a single module.



It has 16 input coincidence with prompt and delayed output, the delay being programmable. The coincidence pattern also is CAMAC programmable as AND, OR or any other combination. It has eight 100 MHz scalars.

OCTAL High Resolution CAMAC ADC, CM88

This module, which is an 8 channel 8K nuclear ADC, has been developed using Peak Stretcher Hybrids and Field Programmable Gate Arrays. It supports individual LOCAL GATE, MASTER GATE and MASTER CLEAR signals.



The conversion time is 8 ms for single channel and 23 ms for 4 to 8 channels. It has DNL of +/- 1% @ 100K counts, INL of 0.02% of the full-scale value.

With the improved ADC resolution as well as higher channel density, the Octal ADC is ideal for germanium detectors in accelerator-based INGA (Indian National Gamma Array) for experiments involving a large number of parameters. An improved version with FERA readout interface is under development

CAMAC TDC Module

A CAMAC TDC module has been designed. It features eight channels and uses the proven ADC section of the CAMAC ADC module with a conversion time of 5 microseconds per channel. This module uses the recently developed TAC hybrid (BMC1522), which has been separately tested. This module features Start, Stop with reset capability and it gives analog voltage ramp proportional to the time interval between the start and stop events.

NIM/TTL to NIM and TTL Level Translator, CM69

This is a general purpose CAMAC module with four channels. It accepts either NIM or TTL inputs and provides a fan out of two on

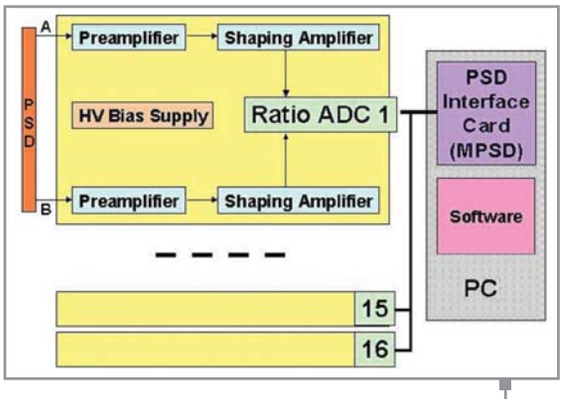
both NIM and TTL outputs. In addition, there is an option to generate a frequency signal in the range of 200 Hz to 20 KHz on channel 4, and to set a level of 1 or 0 through CAMAC command on channel 3. This makes it a very versatile unit in any test and experimental setup.

While keeping pace with the increasing complexity and performance need of nuclear experiments, new developments have been initiated. An embedded CAMAC controller with USB / Ethernet connectivity and FASTCAMAC protocol is under development. Also FERA readout controller, ADC and TDC modules with FERA interface are under development.

Anita Behare <abehere@barc.gov.in>

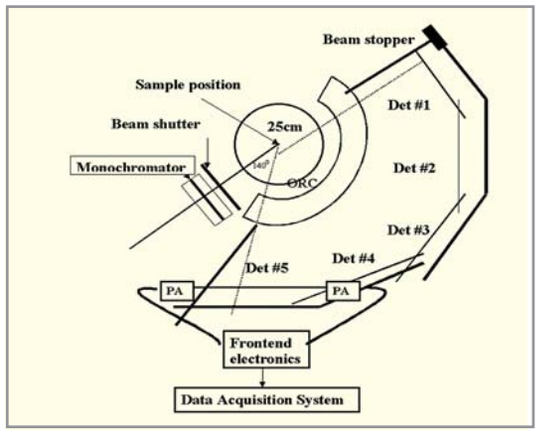
Instrumentation for PSD-Based Neutron Diffractometers

Neutron diffraction is a widely used technique to probe the structure of both crystalline and non-crystalline substances. The diffracted neutrons are detected using linear Position Sensitive Detectors (PSDs) and their angular distribution is recorded as counts over an angular region. This data is analyzed with different techniques to study the properties of the sample.



Block Diagram for Neutron Diffractometers

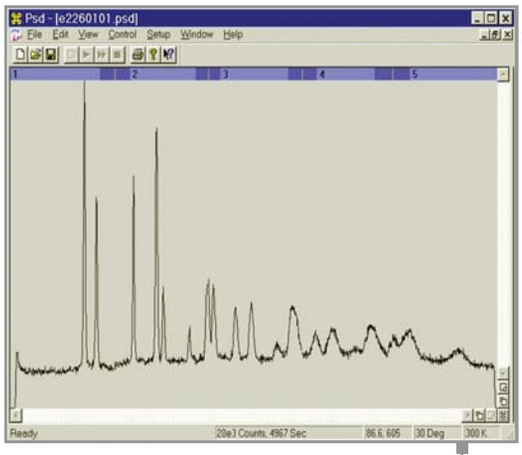
In a single PSD system, data is acquired at different angular positions of the PSD. In order to reduce the experiment time, multiple PSDs are arranged at different angular positions and data is acquired simultaneously from all the PSDs. The instrumentation required for these new PSD-based diffractometer systems as well as the existing systems, was developed. This exercise has greatly enhanced the productivity of these systems.



Use of PSDs is the common factor in all these diffractometers. For each PSD, two Pre-amplifiers (PA), one High Voltage Bias Supply (HV), two Shaping Amplifiers (SA) and one Ratio ADC (RDC) are required. These NIM modules are collectively referred to as the front-end electronics. The addressable Ratio ADCs (RDC) have been developed especially for use in multi-PSD setups.

The PC add-on card MPSD was developed to handle the superset of data acquisition and control requirements of the diffractometers. With MPSD, sixteen RDCs can be connected over a multi-drop FRC cable. The interface card also provides other features like motor controls, monitor control and the discriminator. Data acquisition from a neutron diffractometer and graphical user interface is the main function of the software. Raw data is acquired simultaneously from all the PSDs, each spanning a small angular region. As PSDs are linear, the raw data corresponds to equal increments along the length of PSD. So the data is processed further to obtain equiangular data. This has resulted in better utilization of available beam time. Software also plays a key role in configuring the data acquisition systems for different diffractometers thus achieving the design goal of minimizing development efforts.

High-Q Diffractometer



Diffraction Spectrum of
Crystalline Materials (Nickel Powder)

The Data Acquisition System is being used for Powder Diffractometer for polycrystals, HiQ diffractometer, Powder diffractometers, Polarized Neutron Reflectometer, Quazi-elastic neutron spectrometer, Focusing Crystal based diffractometer, Small Angle Neutron Spectrometer and Polarized Small Angle Neutron Spectrometer.

S.S. Pande <sspande@barc.gov.in>
S.P. Borkar <bsuhas@barc.gov.in>

3.3 ELECTRONICS FOR OTHER PROJECTS

■ Direct Current Potential Drop (DCPD) Technique to Measure the Crack Growth

DCPD System Installed at BARC

DCPD technique based electronics has been developed in MS&ESS and supplied to Materials Science Division (MSD) where it is integrated with the Universal Testing Machine. It is being used in MSD to measure the crack growth in stainless steel, zircalloy and other samples. Similar system is under development for Reactor Safety Division to measure the crack growth in stainless steel pipes.

T. K. Saha <tksaha@barc.gov.in>

■ Programmable Control Electronics for Crystal Pullers

Crystal pullers require very precise and programmable control electronics to pull the crystals. This development has been taken up in MS&ESS. The first such micro-controller based system, using stepper motor and working in micro-stepping mode, has been developed and integrated with one of the crystal pullers in TPPED. It has the capability to pull the crystal at a programmable rate ranging from 0.5 mm / day to 100 mm / day.

■ Dual Phase Lock-In Amplifier

Dual Phase Lock-In Amplifier (Micro-controller based) can display the magnitude & phase of the detected signal and has been developed for signal recovery applications. The full scale sensitivity is 100 nV.

■ Synchro-Hetrodyne Lock-In Amplifier

Synchro-Hetrodyne Lock-In Amplifier simultaneously provides high input dynamic range and outstanding output stability with a full scale sensitivity: 100 nV, signal extraction ratio: 100 dB.

Synchro-Het Lock-in-Amplifier

Three DC arc power supply units have been fabricated and supplied to the spectrograph laboratories of Atomic Minerals Directorate of Exploration and Research at Hyderabad, Tatanagar and Bangalore respectively for analysis of geological samples.

DC Arc Power Supply for Spectrograph Laboratories

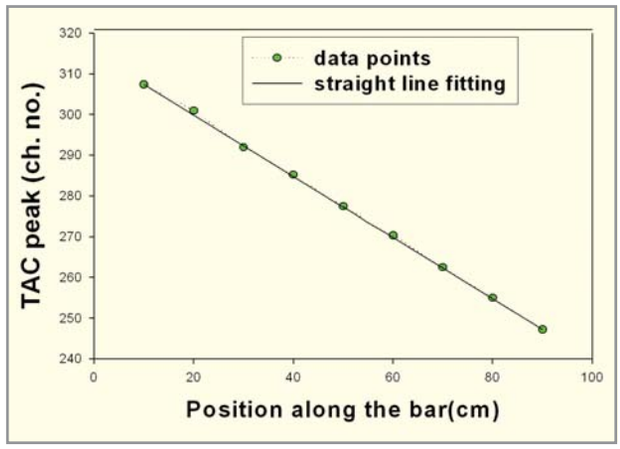
■ Calaendria Tube Sag Measurement System

Calaendria Tube Sag Measurement System has been developed by MS&ESS in collaboration with CDM for use in PHWR. This laser based system can measure sag with an accuracy of ± 0.1 mm. One such unit was supplied to NPCIL.

Sag Profile Measurement System

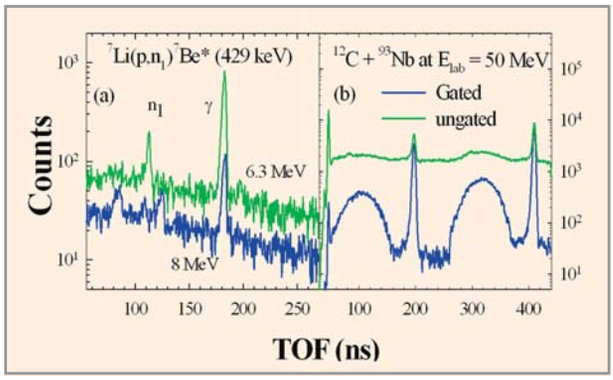
■ Neutron Time of Flight (TOF) Facility for Fast Neutron Measurement

The measurement of neutron spectra is important in many nuclear reaction studies. Measurements of neutron spectra down to $< 1\ \mu$b/MeV with a $\Delta E/E \sim 10\%$ or better are required in some experiments. A large area neutron detector is needed to meet these requirements. In this report, the first test results from such a neutron detector array are presented. The neutron detector array consists of 16 plastic bars with dimensions of 6cm, 6cm, 100cm, each viewed by XP2020 Photo Multiplier Tubes (PMTs) at either ends. The horizontal bars are stacked one above the other on a mechanical stand. Lead absorbers (25 mm thick) are placed in front of the array to attenuate γ-rays. A 30 cm thick mild steel shield consisting of several plates of increasing area can be interposed between the target and the plastic array thus completely shadowing out the target. The shield is used for measuring background neutrons originating from other sources. The position response of one plastic bar was measured with the ^{60}Co source and found to be linear.



The ^{7}Li(p,n)^{7}Be*(429 keV) reaction at E_p = 6.3 and 8 MeV was used to characterize the response of the neutron detector array. The experiment was carried out at BARC-TIFR Pelletron, using a target

of 220 μg/cm^2 LiF on C backing. The mono-energetic neutrons from the reaction were detected in coincidence with 429 keV γ-ray emitted from the first excited state of ^{7}Be. The array was placed at 45^0 with respect to the beam direction and at a distance of 2 m from the target. The Time Of Flight (TOF) of the particles reaching the plastic bars was measured with respect to an array of 7 close packed hexagonal BaF_2 detectors. The neutron group populating the 429 keV state in ^{7}Be can be clearly seen at both beam energies.

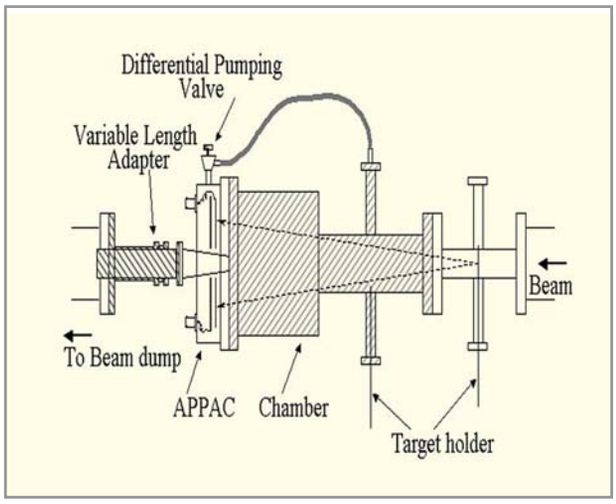


At the higher proton energy the neutron groups from the ^{19}F(p,n) reaction are also present. The neutron detector array was also used to measure the neutrons from the reaction ^{12}C + ^{93}Nb using a pulsed (4.7 MHz) 50 MeV ^{12}C beam bombarding a 93Nb target. Examples of TOF spectra, both ungated as well as gated with the conditions of F > 0 and RF-BGO/BaF_2 prompt are shown.

Dr. V. M. Datar <datar@barc.gov.in>

■ Annular Parallel Plate Avalanche Counter to Tag Reaction Products by TOF

In the study of heavy ion nuclear reactions it is often necessary to make measurements in coincidence with the reaction products to have exclusiveness and also to reduce the background in the data. The slow moving Evaporation Residue (ER) can be tagged by a recoil mass separator or by an array of High Purity Germanium (HPGe) detectors. Both these methods, besides being very expensive, have certain limitations. Another method for tagging is to measure the Time Of Flight (TOF) of the reaction products by a fast timing detector. The identification of the individual product nucleus may not be possible with the TOF, however a good aspect of this is a wide range of the reaction products covered simultaneously. For this purpose, an Annular Parallel Plate Avalanche Counter (APPAC) was built.

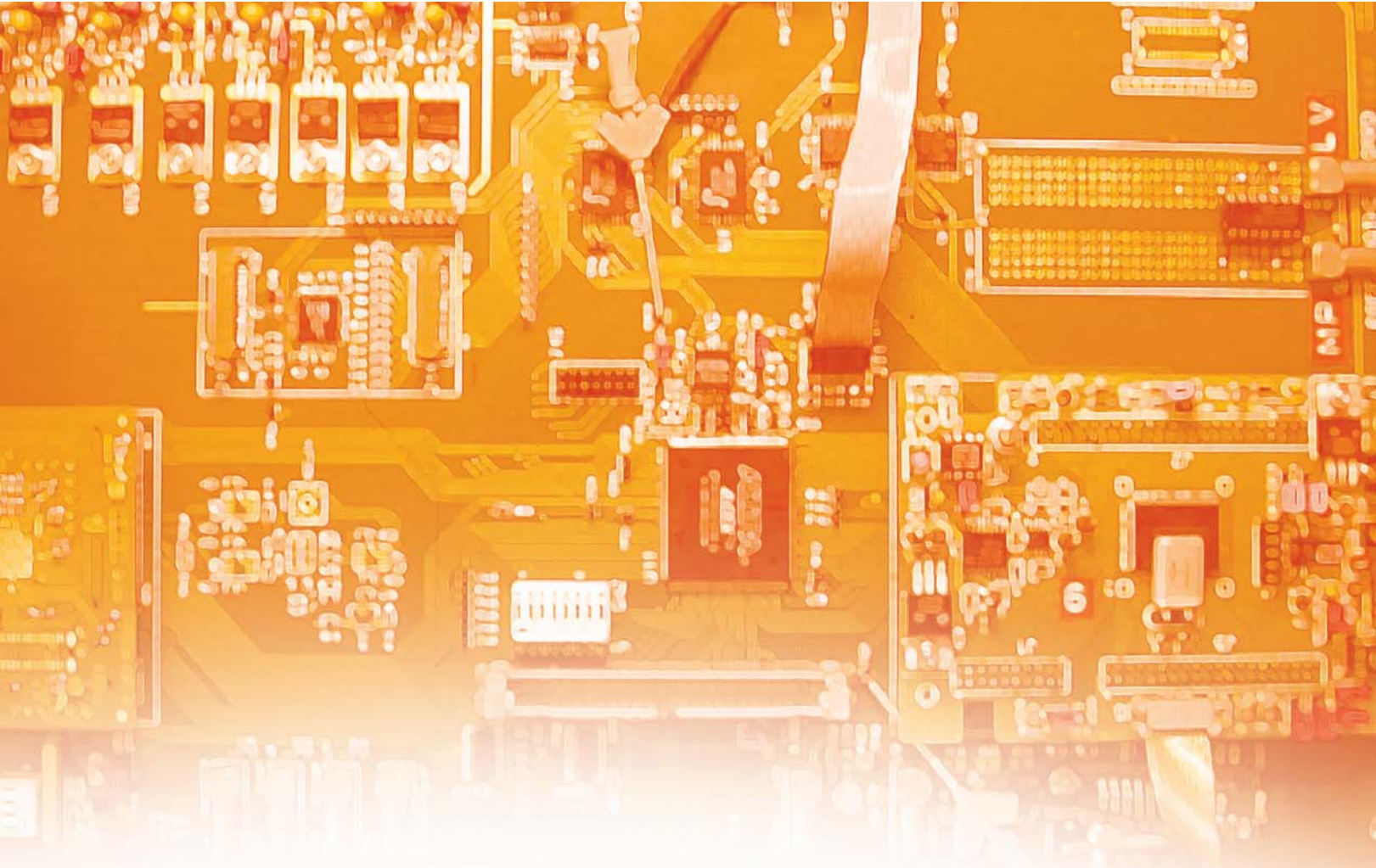


The 240 mm diameter APPAC was fabricated from a block of a special aluminum alloy. The thin mylar entrance window (38 mm ID, 154 mm OD) was supported by a 1 mm thick stainless steel sheet with contoured apertures.

At a distance of 25 cm from the target its angular acceptance is 5°-18°. An upstream target at a distance of 48 cm was also used to accept residues in the angular range of 2.6°-6°. The two electrodes of the APPAC make use of Cu clad PCBs and aluminized mylar foil. The gap between the two electrodes was ~1.5 μm. The target chamber is directly coupled to the APPAC. A variable length adapter coupled to the APPAC at the beam dump side enabled the removal and reinstallation of the detector when required, without disturbing the beam line at either side.

The initial testing of APPAC was carried out using a 125 MeV pulsed beam (9.4 MHz) of ^{28}Si bombarding ^{58}Ni and ^{27}Al targets at the Pelletron. The detector with a 2 μm thick mylar window was operated at ~10 torr of isobutane in the flow mode and at ~500 V across the electrodes. A 130 cc HPGe detector was placed at 90° to the beam and ~10 cm from the target. The APPAC-RF time, APPAC-HPGe time and HPGe energy signals were recorded event by event. It was demonstrated that such a detector would be efficiently used for the separation and identification of evaporation residues from a large background of elastics.

Dr. D. R. Chakrabarty <drc@barc.gov.in>



4. INSTRUMENTS & SYSTEMS FOR RADIATION MEASUREMENT & MONITORING

INTRODUCTION

Radiation monitoring is an essential aid in the control of radiation hazards in the vicinity of nuclear and other radiation installations. BARC has developed a wide range of radiation monitoring instruments to serve specific requirements like personnel monitoring, environmental monitoring and area monitoring in keeping with the latest trends in radiation monitoring technology. Through continuous R&D, BARC also strives to meet the requirements for instruments and systems to implement radiological security and surveillance.

Radiation detectors and nuclear electronic systems are the basic requirements for the measurement and analysis of nuclear radiation. Nuclear Electronics deals with electronic techniques, which are closely associated with nuclear radiation measurement. The Nuclear Electronics systems process the radiation detector signals and supply quantitative information about the different characteristics of radiation, such as type, intensity and energy of the radiation. As a result of years of R&D efforts, BARC has built indigenous capability in the advanced development of state-of-the-art detectors and nuclear electronic systems. An entire range of nuclear electronics from front-end electronics to computer based data acquisition systems has been developed at BARC. Nuclear Instrumentation Modules (NIM) and systems developed in-house have been supplied to many users in BARC and other units of DAE. Technologies for many of these products have been transferred to ECIL and some private manufacturers. Present work aims at miniaturization of circuits for high-density instrumentation. Many hybrid microcircuits have been developed for this purpose. A program for the development of Application Specific Integrated Circuits (ASIC) is under way.

4.1 RADIATION DETECTORS AND APPLICATIONS

■ Auto TLD Badge Reader

With the atomic energy programme in India poised for a rapid growth in the years to come and with increasing use of radiation in radiotherapy, diagnosis, nuclear medicine and industrial radiography, safety of personnel involved in handling radiation sources and security of radioactive materials are of increasing concern to the management. BARC has developed indigenous, passive radiation detectors (i.e. detectors requiring no power source for radiation detection) like the TL (Thermo Luminescent) and the OSL (Optically Stimulated Luminescent) Dosimeters to monitor the radiation exposure of personnel working with radiation. A new TLD badge with machine readable ID code and a compatible auto TLD badge Reader have been developed. The system can process 100 TLD badges at a time and is comparable with some of the best commercial systems available elsewhere in the world. The technology of semi automatic version of this TLD badge (TLDBR-7B) was transferred to M/S Ultratech Laboratories, Bhilai in 2005.

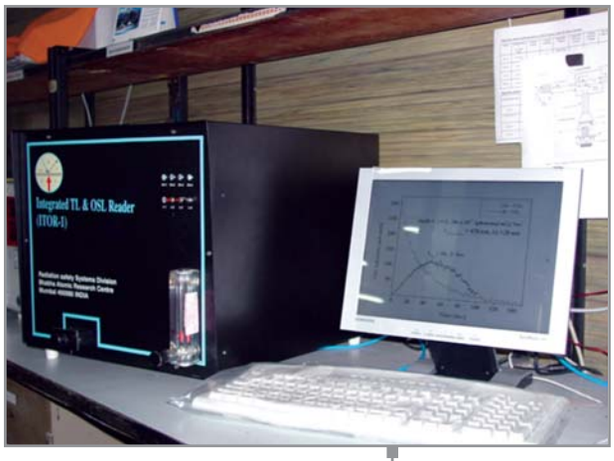
TLD Badge with Machine Readable ID Code

S.Kannan <kannans@barc.gov.in>

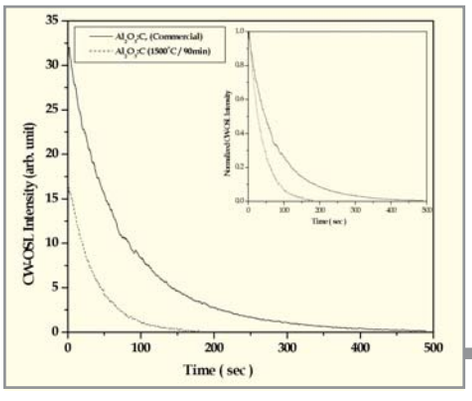
New Auto TLD Badge Reader

OSL Dosimeter Reader

The Optically Stimulated Luminescence (OSL) technique results in improved luminescence efficiency, better sensitivity and simplified instrumentation for personnel and other radiation dosimetry applications. Unlike in thermo-luminescence (TL) dosi meter, where the phosphor is to be heated for readout, no heating is required for the readout process in OSL dosi meter. A prototype PC-based, OSL-cum-TLD Reader has been developed for reading the OSL dosimeters. The reader uses high power blue, green and red LED clusters for optical simulation of different phosphors. The stimulation can also be selected to be Constant Wave (CW), Pulsed (P) or Linear Modulated (LM) to suit various applications. Elaborate filter systems are used to separate the signal from the stimulating light source.



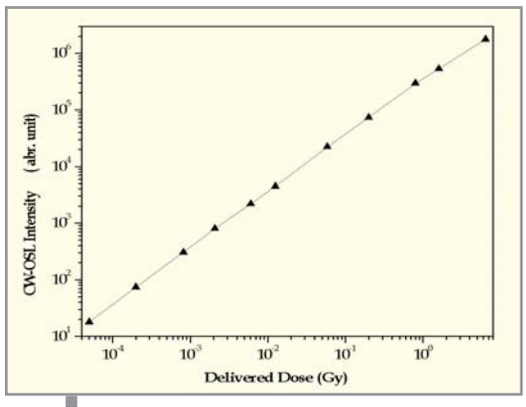
OSL Reader



OSL Response of the Processed and Commercial Al_2O_3:C Samples for 12.5 mGy Beta Dose. The Inset Figure Shows Normalized OSL Intensity

A highly sensitive single crystal anion defective α-Al_2O_3:C phosphor has been developed by diffusing carbon in crystalline sapphire plate. The developed α-Al_2O_3 samples are found to have a linear response from the minimum measurable dose of 50 μGy up to 1 Gy ($\pm$ 3σ) with an indigenously developed OSL Reader.

OSL Dosimeter 5mm x 5mm x 0.4mm



OSL Response of the Processed Sample Relative to $^{90}Sr/^{90}Y$ Beta

S.Kannan <kannans@barc.gov.in>,

M.S.Kulkarni <kmukund@barc.gov.in>

Electronic Pocket Dosimeter

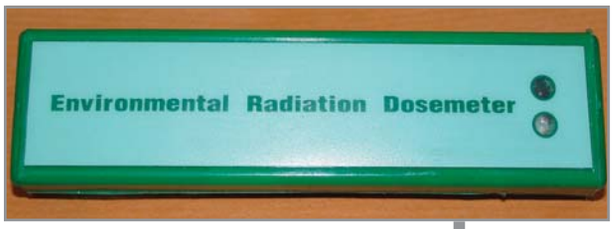
The passive dosimeter badges like TLD or OSL badges are read only periodically (e.g. once in a month). Hence, radiation workers are required to use an on-line dosimeter, preferably with an audio alarm to warn against high radiation exposure. A micro-controller-based low-cost electronic pocket dosimeter with alarm

facility has been developed in BARC for this purpose. The dosimeter indicates both dose rate and cumulative dose. A non-contact optical RS232C interface is provided in the dosimeter for entry of parameters like calibration factor, ID number of the wearer, dose rate and dose alarm through a PC.

S.Kannan <kannans@barc.gov.in>

Environmental Dose Data Logger

It is also important to have continuous environmental radiation surveillance in and around radiation and nuclear energy installations to ensure safety of the people living around these installations. TL dosimeters and a compact electronic dose data logger developed in BARC are used for environmental radiation monitoring. The dose data logger, based on a tiny micro-controller, is capable of working continuously for four months



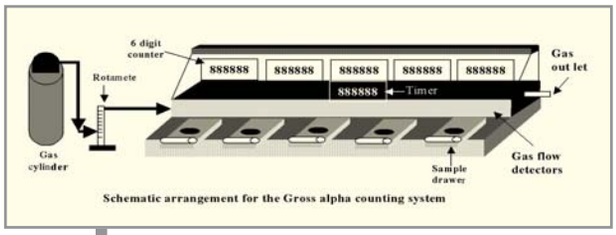
Environmental Dose Data Logger

without battery change. It stores weekly doses and latest daily doses for seven days in a built-in non-volatile EEPROM. It has an optical RS232C interface to a PC or a Simputer for downloading the dose data, entering the calibration factor, setting the issue time / device ID and switching the unit ON/OFF.

S.Kannan <kannans@barc.gov.in>

Multi-Channel Gross Alpha-Counting System

To ensure safety in work places where there is a probability that alpha emitting nuclides can be air borne, a gross alpha-counting system has been developed using indigenously developed multi-wire gas flow proportional counter. The system can count simultaneously five samples.



Schematic Arrangement for the Gross Alpha-counting System

Large area multi-wire gas flow proportional detectors (~ 700 cm^2 sensitive area) developed in BARC are also used to monitor alpha contamination of decontaminated laundry.

D.A.R. Babu <rajubabu@barc.gov.in>,
G. Krishnmachari <charigk@barc.gov.in>

Tritium Monitors

BARC has also developed continuous tritium-in-air and Tritium-in-water monitors to provide internal exposure control and protection for the workers in Heavy Water reactors and facilities handling Tritium. The monitors use a plastic scintillator sponge packed flow cell, made of Aluminium or stainless steel body with Perspex or Teflon window as detector. The detector is coupled to a matched pair of photo multipliers and measurement is made in coincidence mode of counting.

Tritium-in-air Monitor

Radiation monitors using compensated Ion chamber technique have been in use in nuclear power plants and facilities for measurement of Tritium Activity in presence of gamma background. An electronic system based on auto-ranging electrometer is developed with provision for selecting alarm-level and remote data logging on PC or Notebook computer using RS232 serial link and RadNet protocol. The over all system incorporates an indigenously developed 40 Litre Ion-chamber and pumps for circulating air through the chamber. The data acquisition and I/O processing is carried out using Philips 80C552 micro-controller based hardware.

A. Narayanan <anarayan@barc.gov.in>,
G. Krishnmachari <charigk@barc.gov.in>

Portal, Limb and Vehicle Monitors

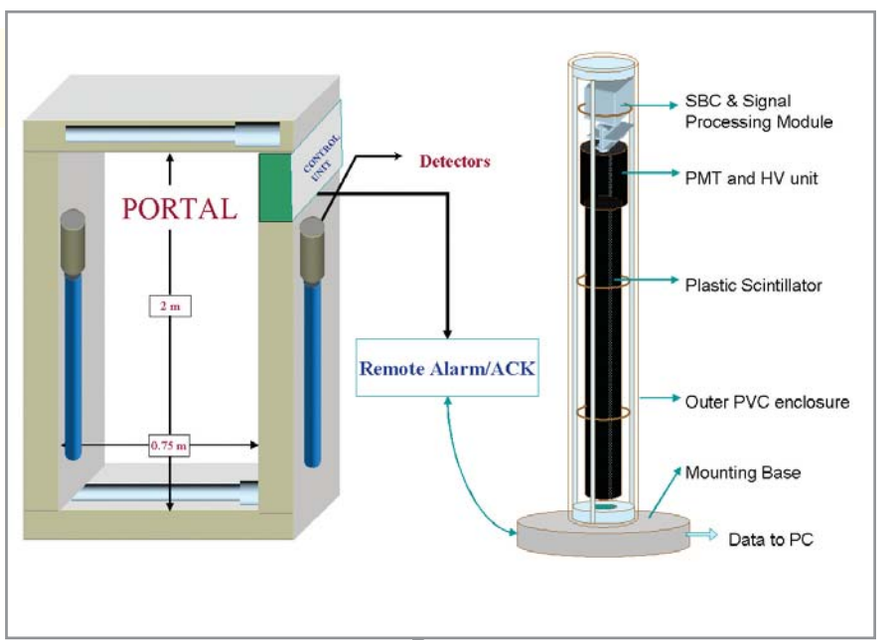
For ensuring security and restricting the movements of radioactive sources and special nuclear materials, BARC has developed very sensitive Portal Monitors, Limb Monitors and Vehicle monitors.

The Portal Monitor basically comprises of four plastic scintillators (5 cm diameter and 50 / 100 cm long) coupled to PMTs and a micro-controller based single board computer.

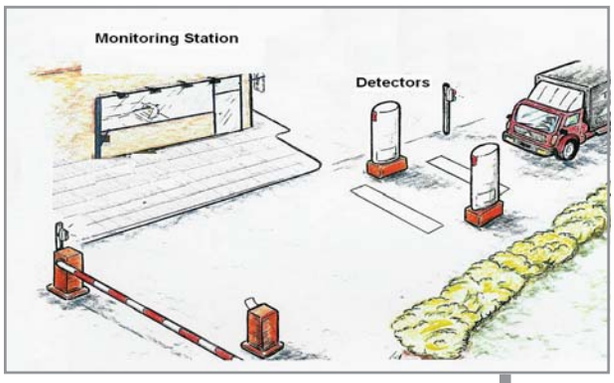
The system has a sensitivity of 200 milligrams for Pu and can detect a few micro-curies of Cs-137 or Co-60. For specific requirements of neutron detection, a Helium - 3 neutron detector can also be included in the system.

The Limb Monitor, which is also based on plastic scintillation detector, is capable of inconspicuous deployment for the detection of movement of radioactive material in public places. The monitor can detect 500 mg of Pu-239 or 800 grams of natural Uranium or 5 micro-curie of Cs-137 one meter away from the system.

The vehicle monitoring system is PC based and it consists of two detector units, each having three plastic scintillation detectors of 50 mm dia x 500 mm long. The unit is sensitive enough to detect 1 MBq of Cs-137 or 0.3 MBq of Co-60 from a distance of 3 meters. The system has facility for background subtraction, false alarm suppression and a battery backup for uninterrupted usage. The technologies of the portal, Limb and vehicle monitors have been transferred to ECIL, Hyderabad, for production.



Portal and Limb Monitors

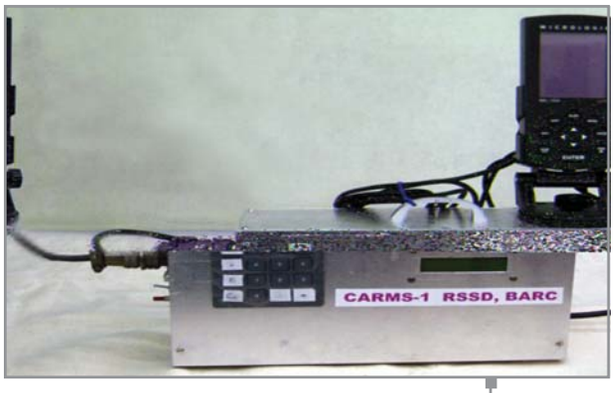


Vehicle Monitoring System

M. Hari Kumar <mhari@barc.gov.in>,
G. Krishnmachari <charigk@barc.gov.in>

Compact Aerial Radiation Monitoring System (CARMS)

A gamma radiation dose rate monitoring system based on multiple GM detectors has been specifically developed for radiological mapping of areas in the vicinity of power stations and for use in Remotely Piloted or Unattended Aerial Vehicles (RPVs/UAVs). The compact, battery-operated system, based on a lap-top PC, integrates the radiation dosimeter with a Global Positioning System (GPS) to provide the positional and radiological information remotely through a radio modem.



The Compact Aerial Radiation Monitoring System (CARMS)

N. Padamanabhan <npadma@barc.gov.in>,
G. Krishnmachari <charigk@barc.gov.in>

Portable Compact Gamma Spectrometry System (PCGS)

A Portable Compact Gamma Spectrometry (PCGS) System based on NaI(Tl) detector has been developed for a quick assessment as well as characterization of ground contamination arising due to fallout of radionuclides. The system will be very useful for the planning of counter and control measures in case of radiation emergencies including nuclear attacks. The PCGS System records gamma ray spectra of the radionuclides from the surroundings using a 256 Channel MCA. The Gamma ray spectra acquired

Compact Gamma Spectrometry System

using NaI(Tl) (3"×3") detector, are stamped with positional coordinates including Greenwich Mean Time (GMT) using Global Positioning System (GPS), which receives signals from Navigational satellites. The on-line data is downloaded and processed on a Notebook PC during surveys and the processed results are mapped onto the map of the area to be surveyed. The system can also be used to locate orphan radioactive sources. The system is powered by a 12 V DC source and it can be used for survey in any mobile platform.

G. Krishnmachari <charigk@barc.gov.in>

ELECTRET Dosimeter

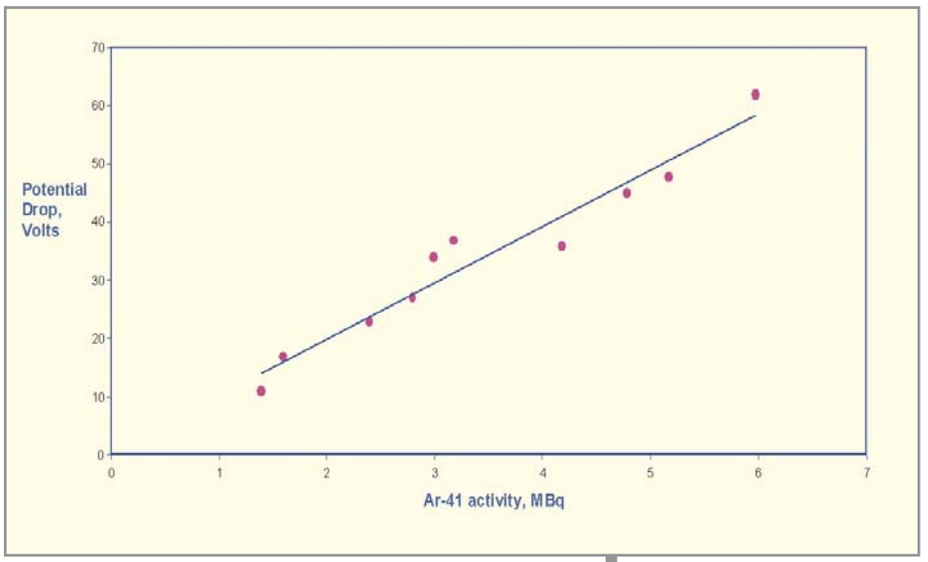
Electret is a piece of dielectric material on which quasi permanent electric charges are stored. The charge on the electret produces a strong electric field, capable of collecting ions of opposite sign. Due to this property of producing and retaining such high electric fields, electrets can be used in several areas of radiation protection practices.

Electret technique was used for measurement of ^{41}Ar release from a nuclear reactor. A small amount of air from the exhaust ventilation duct of the reactor was drawn into a sampling chamber loaded with electret. ^{41}Ar in the exhaust air ionizes the air inside the chamber. Electrons and negative ions neutralize a fraction of positive charge of the electret and the drop in the potential of the electret is a measure of the integrated information of ^{41}Ar release during the sampling period. Calibration of the system was done by standard Marinelli Cup method using gamma ray spectrometry. A graph of ^{41}Ar activity passing through the chamber and the voltage drop of the electret gives a very good correlation coefficient of 0.974 and a slope of 9.7 V MBq^{-1}. There is good agreement with the gamma spectrometric measurement of release.

Electret technique has also been developed to measure exposure due to X-rays. Electret X-ray Dosimeter offers an effective and economic tool in the measurement of leakage radiation dose around an X-ray machine.

Electret Chamber for ^{41}Ar measurement with Charge Reader

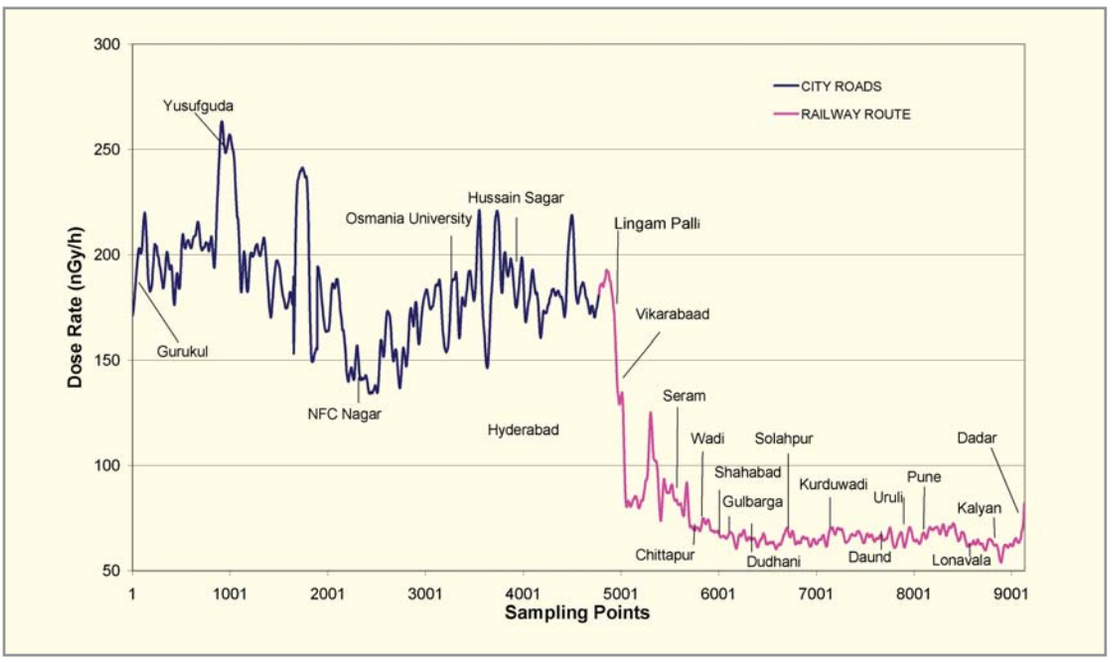
Neutron detection using an electret is accomplished by coating the inside surface of a bakelite chamber with ^{10}B. The interaction of thermal neutron with ^{10}B results in emission of alpha particles, which ionize the air inside the chamber. The drop in the potential of the electret for neutrons from an Am-Be source (neutron flux = 2.2 x 10^5 n/cm^2/sec) was systematically studied for various moderating thicknesses of HDPE. The optimum thickness of polyethylene was found to be 3 cm for a ^{10}B thickness of 0.6 mg cm^{-2}. A potential drop as good as 7.5 h^{-1} was obtained. The result of this study offers a scope for the development of neutron dose measurement and electret based neutron dosimetric system.



Calibration of ELECTRET Chamber for Ar^{41} Measurement

Environmental Radiation Monitoring

Environmental radiation monitoring is being carried out to assess the radiation levels to estimate public exposure to radiations on a continuous basis. The method involves placing radiation detectors at different places to assess the exposure rate. Conventional methods have limitations as they provide data only about the areas where these detectors are placed. Indigenously developed mobile radiation monitoring systems are used to conduct radiation mapping covering many rail-road routes, city areas and Emergency Planning Zones (EPZ) of Indian Nuclear Power Plants (NPP).

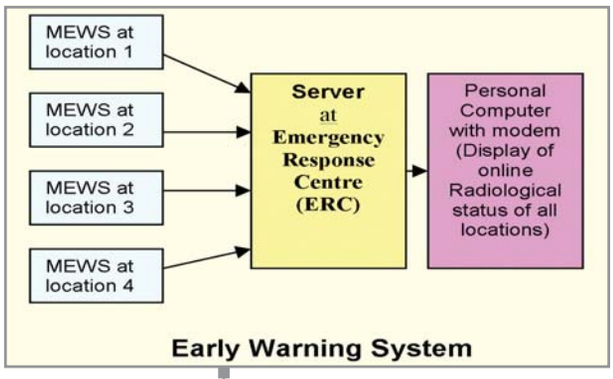


Using various mobile monitoring systems such as Compact Aerial Radiation Monitoring (CARMS), Aerial Gamma spectrometry System (AGSS), Compact Mobile Gamma Spectrometry System (CMGS) etc. radiation surveys are being carried out frequently for the generation of gamma background radiation mapping of the country. Data collected compares well with the normal expected values obtained by the conventional methods. The typical graph given shows results obtained from radiation surveys carried out at Hyderabad and enroute to Hyderabad. It is planned to carry out aerial surveys of all EPZ of NPPs and mobile monitoring survey of all major cities of India to help assess the impact of any nuclear or radiological events or impact of operation of NPP on the surrounding environment and the public in particular.

Pradeepkumar K.S. <pradep@barc.gov.in>

Online Environmental Dose Rate Acquisition System

BARC has developed a computer based radiological surveillance system for nuclear facilities. This system can acquire dose rate data due to radioactive releases from any nuclear facility, environmental radiation background and any unauthorized movement of radioactive source through the exit points. The system is designed for use during normal operation of the plants and for emergency preparedness and response. A large number of MODEM based Early Warning Systems (MEWS), which are micro-controller based low-level gamma monitors, located in and around the plant interact with a central computer server unit located at emergency response centre on near-real time basis. The server interrogates the node unit at selected intervals, receives data and displays on the site map along with the date, time and dose rate. The online data is stored in Access database for quick retrieval at user's request for detailed processing to assess the impact of any nuclear or radiological emergency situation and help in implementation of counter measures. The necessary software was developed for assessing the environmental radiological status around the plant using the network of gamma monitors during normal operation and for emergency preparedness. This system has demonstrated its capability to respond to any increase in radiation level and hence acts as an Early Warning System.



Early Warning System

Pradeepkumar K.S. <pradep@barc.gov.in>

Gas Filled Radiation Detectors

Various types of sensors are used in nuclear facilities such as reactors, particle accelerators, radiological labs etc. for detection and measurement of radiation both from the point of view of process control and personnel protection. In these facilities the emphasis is on the gross measurement of ambient radiation intensity rather than spectroscopic measurements. Among the various types of detectors, gas-filled devices are preferred for their robustness, simplicity of operation, flexibility in design, long-term stability and reliability. In all gas-filled radiation detectors, the ionization produced by the incident radiation generates an electrical signal, which is indicative of the intensity of the radiation falling on the sensitive volume of the detector. The signal can be collected either as a DC current (ionization chambers) or as individual pulses (proportional and GM counters).

Development of ion chamber-based radiation detectors is in progress at BARC since last several years. Some of these devices include fission detectors with parallel plate configuration for reactor start-up applications, Spherical Ion chambers for Environmental Monitoring, Re-entrant type ionization chambers for isotope calibration, Boron lined uncompensated ion chambers for reactor safety and control, Self Powered Neutron Detectors and Tritium chambers.

Some of the devices are:

- Failed Fuel Detection and Location system consisting of 36 ion chambers arranged in a special matrix with the signals obtained from them being constantly

monitored for coolant gamma activity.

- A prototype non-contact nucleonic thickness gauge employing ionization chamber for on line transmission type thickness gauging system for industrial application in India.

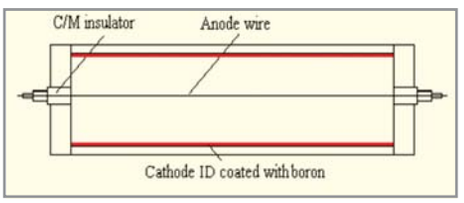
Detailed theoretical studies on gamma ion chambers have been carried out and they have been found to be extremely useful. Some of the current activities include

High-Temperature Fission Detectors for PFBR

These are specialized type of detectors that need to operate at 600°C and with gamma exposures up to 1MR/h

Boron Lined Counters

These cylindrical detectors are useful during reactor start up as well as during neutron area monitoring.

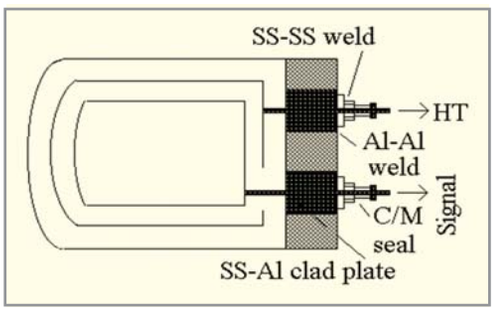


^{3}He Counters

Prototype helium-3 counters have been developed for neutron area monitoring applications.

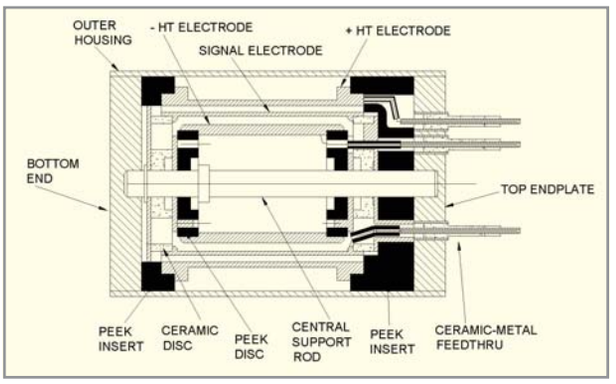
High-pressure Gamma ion chamber

A High-pressure Gamma ion chamber-sensitive to low energy and suitable for environmental monitoring- has been developed and technology has been transferred to ECIL, for commercial production.



Gamma Compensated Boron lined Ion Chambers with Polyetherether Ketone (PEEK) Insulating Spacers

These detectors exploit the ease of machine-ability of PEEK and have been developed for various reactor applications.

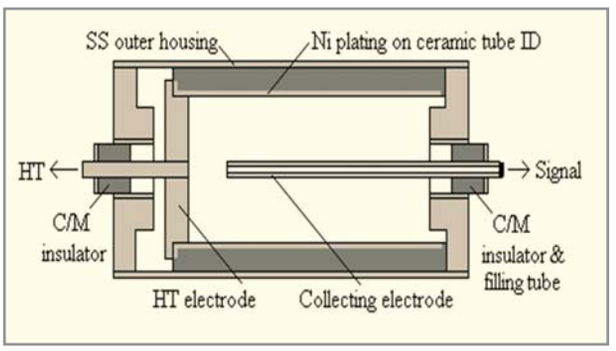


Ion Chambers for Use in Accelerators

Gamma sensitive ion chambers suitable for beam-loss monitoring applications at Indus-II accelerator facility at RRCAT, Indore are being developed.

High Range Gamma Ion Chambers for Space Critical Applications

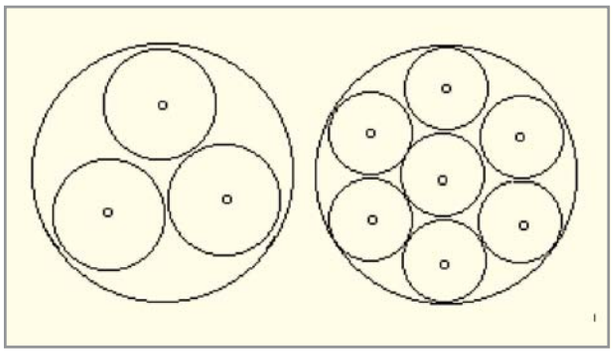
Gamma ion chambers with dimensions comparable to that of a GM counter have been developed for measuring gamma fields of the order of 1R/h to 1KR/h.



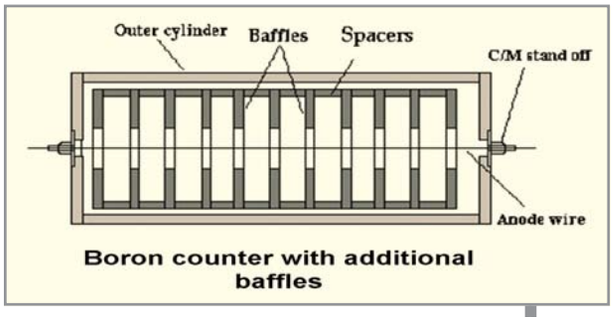
Innovative Techniques

Several innovative modifications have been incorporated in conventional detectors for improved sensitivity and performance. Some of the developments include:

- Boron counters for enhanced sensitivity
- Multiple cathode structure provides improved sensitivity.

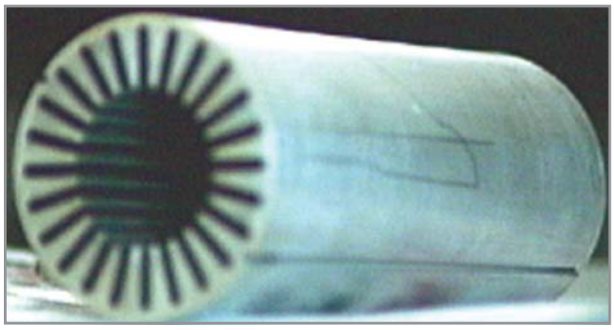


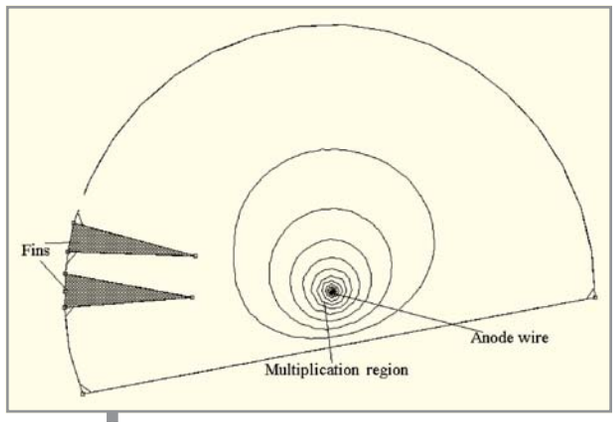
- Introduction of additional structures within the sensitive volume has resulted in improvement in neutron sensitivity.



Boron Counter with Additional Baffles

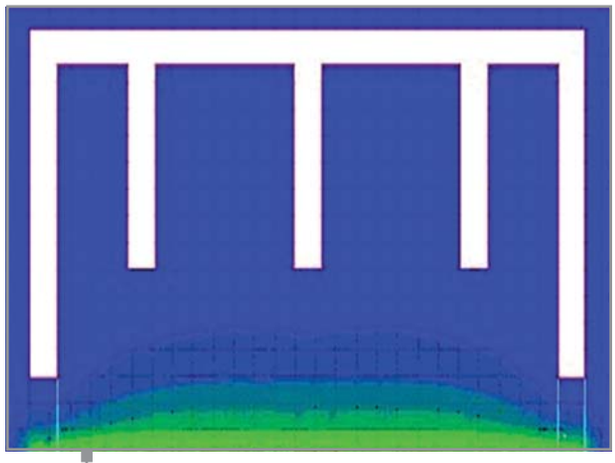
- Boron counters with boron-coated fins provide better mechanical ruggedness and improved neutron sensitivity.



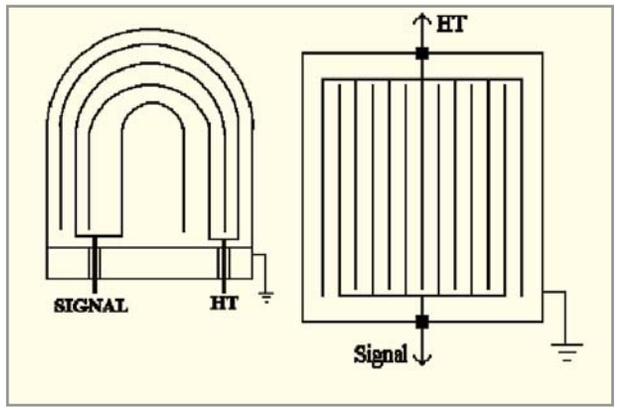


Electric Field Distribution in Fin Structure

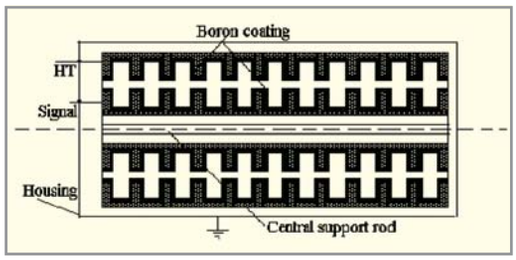
- Multiple electrode ion chambers (with 4 and 12 shells) to improve collection efficiency and range of measurement for RRCAT and Hot Cell facilities.



Electrical Field Distribution between the Anode Wire and the Baffles in a Boron Counter

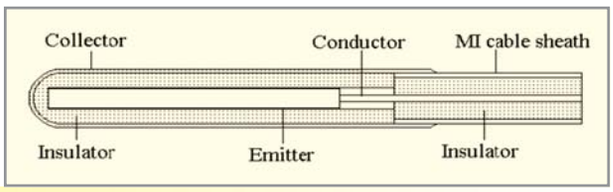


- Addition of annular discs and spacers in the inner and outer surface of standard cylindrical geometry improved the neutron sensitivity by a factor of 3.7.



Self Powered Neutron Detectors with Inconel Emitter

An Inconel600 (2 mm dia x 21 cm long) self-powered neutron detector has been developed as an alternative to platinum and cobalt detector. This detector works on the basis of (n,γ-e) prompt reaction and will be useful for reactor control and safety.



Design innovations in neutron and gamma detectors" K.R.Prasad, **Nuclear and Radiochemistry symposium** (2003)

Boron-lined proportional counters with additional electrodes, P.M. Dighe, K.R. Prasad, S.K. Kataria, S.N. Athawale, A.L. Pappachan, and A.K. Grover, **Proceedings of 15th National Symposium on Radiation Physics (NSRP-15),** BARC, Nov.12-14, 2003

Development of an Inconel self powered neutron detector, Mary Alex, K.R.Prasad and S.K. Kataria, **Proceedings of 15th National Symposium on Radiation Physics (NSRP-15),** BARC, Nov.12-14, 2003

Device to increase the dynamic range of high pressure ionization chambers used in environmental radiation monitoring, V. Balagi, K.R. Prasad, R.K. Jakati and S.K.Kataria, **Review of Scientific Instruments,** Vol. 74, No. 12, Dec 2003

Indigenous development of gamma compensated boron lined neutron chambers, Mary Alex, D N Prasad, K R Prasad, S K Kataria, S N Athavale, A L. Pappachan, C Subramanian, A K Grover, and A K Sur, **Journal of Scientific and Industrial Research,** 62, 2003 pp.1057-1062

Boron-lined proportional counters with improved neutron sensitivity, P.M. Dighe, D.N. Prasad, K.R. Prasad, S.K. Kataria, S.N. Athavale, A.L.Pappachan and A.K. Grover, **Nuclear Instruments and Methods in Physics Research** (A), 496, 1 pp 154 – 161 (2003)

Principles and applications of gas-filled radiation detectors, K. R. Prasad, V. Balagi, P. M. Dighe and Mary Alex, **IANCAS Bulletin** (2004)

Effect of high gamma background on the neutron sensitivity of fission detectors, V.Balagi, K.R. Prasad and S.K. Kataria , **Indian Journal of Pure and Applied Physics.** (2004)

Silver lined proportional counter for detection of pulsed neutrons, P.M. Dighe,, K.R. Prasad and S.K. Kataria, **Nuclear Instruments and Methods (A)** Vol.523, Issues 1-2, 158-162, May 2004.

Development of neutron chambers with improved electrode design, Mary Alex, D.N. Prasad, K.R. Prasad and S.K. Kataria, **Nuclear Instruments and Methods-A,** Vol.527, Issue-3 Pgs.562-566, July 2004

V.Balagi <balagiv@barc.gov.in>,

P.M.Dighe <pmdighe@barc.gov.in>

Silicon Detectors for CERN

BARC is a collaborative partner towards the 'Preshower Silicon Sensor' for the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC), CERN under India CMS collaboration. LHC is the largest particle accelerator–collider being built at CERN and scheduled to be commissioned in 2007. The CMS is the detector assembly involving different types of particle detectors and it will use the preshower silicon strip detectors in front of the two crystal end cap modules.

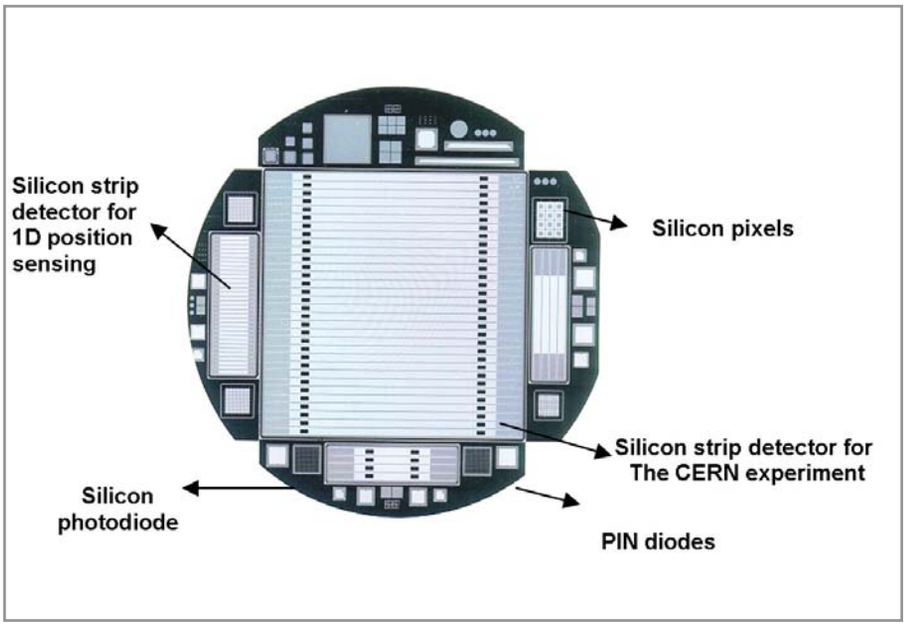
BARC has recently developed the technology for fabrication of Preshower Silicon Detectors (PSD). Such detectors in the form of 1000 micro modules will be supplied to CERN. This work involves fabrication of detectors at a foundry (BEL, Bangalore) and subsequent assembly to make micro modules. The radiation hard front-end electronics is beeing developed at CERN and it will be integrated later to the detector by CERN. The detectors have to qualify through several dc and dynamic tests as specified by CERN.

Detector Fabrication

The development of PSD was carried out in collaboration with CEERI, Pilani and BEL, Bangalore, The process at BEL has been optimized and the production of detectors has been started at BEL. More than 700 detectors have been produced out of a target of 1000.

Along with the strip detector, some other types of detectors have been designed and are being developed for DAE applications.

The silicon PIN diodes of various geometries are being produced for other applications such as pocket dosimeters. The detectors fabricated at BEL have been qualified by the test procedure specified by CERN and they also meet the requirement of radiation.

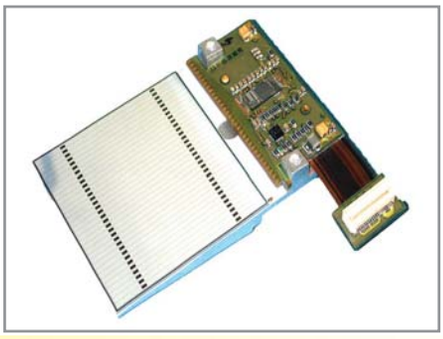


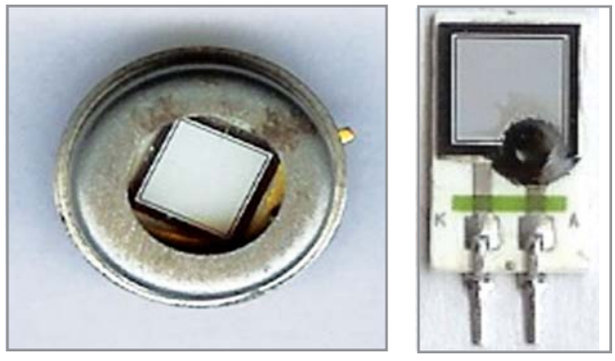
Detector Micro Module

The strip detectors will be delivered to CERN in the form of micro modules in which the detectors are assembled on the ceramic tile, which would contain the radiation hard front-end hybrid, and the ceramic will be mounted on an aluminum tile.

R&D for other types of Silicon Detectors

Other types of silicon detectors viz. PIN photodiodes are being developed for several applications in DAE such as high resolution spectroscopy of charged particles, large area detectors for low activity counting, strip detectors for nuclear physics experiments, FET based dosimeters, etc.





Liquid Scintillation Counting (LSC) Systems

LSC systems are utilized for measurement of radioactivity particularly low energy betas emitted by tritium and carbon. Development of LSC systems was initiated in 1995. Earlier systems were microprocessor-based and used SCA-based design. Subsequently, Personal Computer based LSC systems, which make use of MCA's for windowless counting have been developed. Powerful user-friendly software is developed for calibrations and quenche corrections.

LSC System with Normal Background

The system consists of manually-operated sample changer containing light tight sample chamber in which a pair of PMTs is mounted along with preamplifiers. The signals available from preamplifiers are processed using a PC plug-in "LSC Signal Processing Card" which contains various circuits such as

CMS preshower silicon strip detector for the LHC, CERN: Reliability of detectors and trials for assembly, Anita Topkar, Praveenkumar S, Bharti Agrawal, SK Kataria, **DAE-BRNS symposium on Nuclear Physics,** December 8, 2003.

Indigenous Technology Development for High Energy Resolution Silicon PIN Diode Detectors, Anita Topkar, Praveenkumar S, Bharti Agarwal, **DAE-BRNS symposium on Nuclear Physics,** Varanasi, December 2004

Anita Topkar <anita@barc.gov.in>

coincidence detection circuit, gated amplifiers, shaping circuits and high resolution MCA. Beta energy spectrum (corresponding to coincident events) is acquired and displayed. The spectrum is further analyzed to final quench corrections and efficiency using SIS method. Powerful user-friendly software has been developed for this purpose. The system gives efficiency of nearly 50% for tritium counting using toluene based samples. The background of nearly 20 cpm is obtained in tritium window. More than 10 such LSC systems have been delivered to users.

LSC Systems for Alpha / Beta Discrimination

This system makes use of pulse shape analysis for α/β discrimination. A new method called selective gate integration, which can give discrimination errors as small as 1-2% for properly prepared samples has been developed. In this system α/β energy spectra are also acquired and displayed for further analysis.

LSC with Low Background

Development of low background 'LSC System' (< 5 cpm in tritium window) has been undertaken. A new method of background reduction (using pulse shape analysis) has been developed to give background of nearly 5-7 cpm in tritium window.

LSC system with Automatic Sample Changer

Development of this system has now been undertaken at BARC. System electronics has been developed at BARC and the mechanical fabrication is being carried out in collaboration with industry.

(NSRP-15), BARC, Nov.12-14, 2003

A very low background liquid scintillation counting system using active shielding techniques", Raivinder Kaur, S.R. Jadhav, P. Shalakha, P.P. Vaidya, S.K. Kataria, **Proceedings of 15th National Symposium on Radiation Physics (NSRP-15),** BARC, Nov.12-14, 2003

Embedded Software Development for MCA Systems, S.S. Pande, C.P. Kulkarni and M.D. Ghodgaonkar, **SNI-2004 symposium,** IGCAR, Kalpakkam, February 17-20,2004

Compact 8K Multichannel Analyzer with USB interface and multimode operation, C.P. Kulkarni, M. Vinod, M. Paulson, P.P. Vaidya, M.D. Ghodgaonkar and S.K. Kataria, **Compact Nuclear Instruments and Radiation Detectors,** Defence Lab., Jodhpur, March 2-4,2005,

An Overview of Batteries for Compact Nuclear Instrumentation and Embedded Systems, C.P. Kulkarni, **CNIRD-2005**

Development of Low Cost Microcontroller based Portable Spectroscopic System", M. Vinod, Molly Paulson, P.P. Vaidya, M.D. Ghodgaonkar, S.K. Kataria, S.K. Bharade and Harish Dewan, **CNIRD-2005**

P. P. Vaidya <ppvaidya@barc.gov.in>

4.2 NUCLEAR INSTRUMENTATION AND SYSTEMS

■ High Voltage Systems

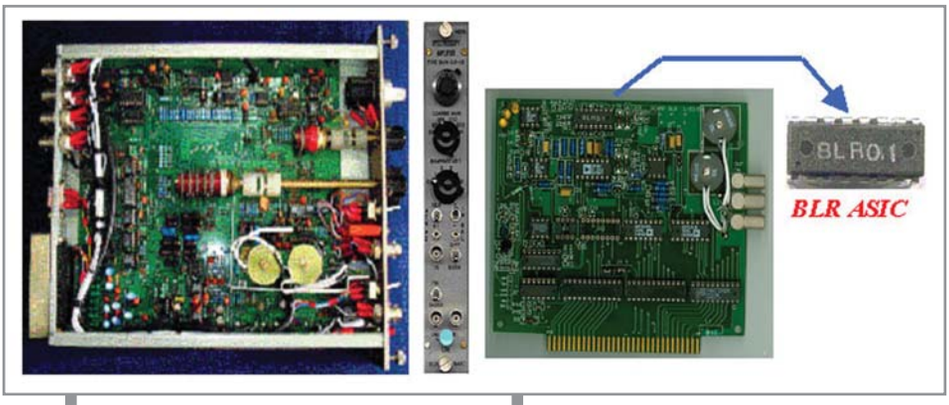
A 2.5KV/1mA single supply NIM module suitable for photo-multipliers and a 5 KV supply suitable for HPGe and Si (Li) developed in BARC are now marketed by ECIL. Computer controlled multiple HV systems suitable for photo multipliers providing 80 independently programmable HV channels per crate (marketed by ECIL) have been used in the TACTIC gamma ray telescope (GRACE project) of NRL at Mount Abu. A new 256 channel HV system consisting of 16 channel HV modules is under development. In this system, four types of specially designed hybrid microcircuits are used for compactness and enhanced reliability. A 32-channel version of the HV system with a LAN interface is already in use.

Computer Controlled 256 Channel HV

16-Channel HV Module

32-Channel HV Crate

P.K.Mukhopadhyay
<pkmuk@barc.gov.in>

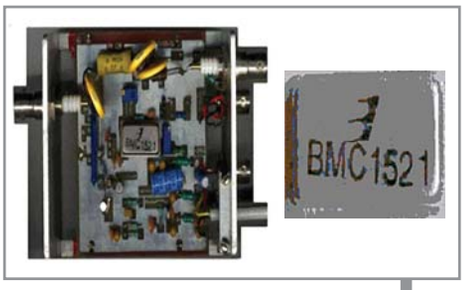


Spectroscopy Amplifier

PC Based Pulse Shaping Amplifier

Preamplifiers

A type of charge sensitive preamplifier with low dynamic input impedance has been supplied in large numbers for use with linear position sensitive detectors in neutron diffraction spectrometers at DHRUVA. A recently developed preamplifier suitable for proportional counter, surface barrier and PIN detectors, uses a hybrid BMC1521.

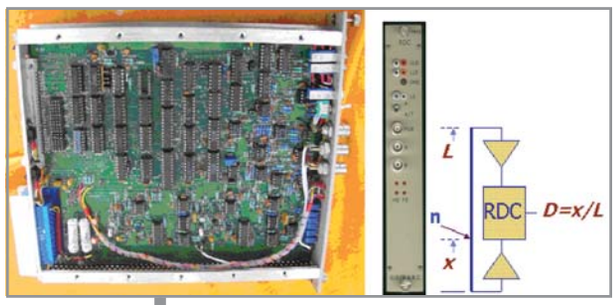


Charge Sensitive Preamplifier

P.K. Mukhopadhyay <pkmuk@barc.gov.in>

Ratio to Digital Converter

The Ratio to Digital Converter (RDC) provides direct digital output of the ratio of two pulses. It has been used in large numbers for position encoding of position sensitive detectors in the neutron diffraction spectrometers at DHRUVA. The technology has been transferred to ECIL.



Ratio to Digital Converter

P.K. Mukhopadhyay <pkmuk@barc.gov.in>

Pulse Shaping Amplifier

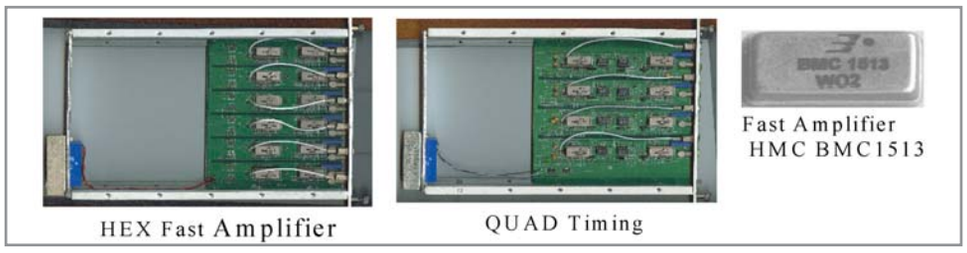
A shaping amplifier (marketed by ECIL as model PA4901N) has been used in large numbers in the neutron diffraction spectrometers at DHRUVA.

A PC-based shaping amplifier with programmable gain and PZ adjustment suitable for dedicated counting systems has been developed. It uses a BaseLine Restorer (BLR) ASIC designed in BARC and fabricated at BEL.

P.K. Mukhopadhyay <pkmuk@barc.gov.in>

Fast Pulse Amplifiers for Timing

These are fast pulse amplifiers with low-rise time (<3nS). A large number of Hex Fast Amplifiers have been manufactured in ECIL and used in the TACTIC telescope at Mount Abu. Timing filter amplifiers are fast amplifiers with the option of a low time constant integration in the signal path for optimum performance in some experiments. A large number of Quad Timing Filter Amplifiers have been used in PELLETRON, at TIFR. New version of these amplifiers is based on a fast amplifier in the form of an HMC.



Design of remote logging radiation detector probes, P.K. Mukhopadhyay, P. Satish and V. D. Srivastava, **Proceedings of 15th National Symposium on Radiation Physics (NSRP-15),** BARC, Nov. 12-14, 2003

Development of Hybrid HV Supply for Grace Instrumentation, A.Manna, A.Mishra, S.G. Thombare, P.K. Mukhopadhyay, J. Bhattacharya, **NSNI-2004 symposium,** IGCAR, Kalpakkam, February 17-20, 2004

Baseline Restorer ASIC and its Applications, P.K.Mukhopadhyay, Prafulla Satish, V.D.Shrivastava , S. Yadav, Y.Rejeena Rani and Y. P. Prabhakar. Rao, **NSNI-2004 symposium,** IGCAR, Kalpakkam February 17-20, 2004

A Ratio to Digital Converter with Parallel Interface", P.K. Mukhopadhyay, P. Satish, V.B. Chandratre and V.D.Srivastava, **NSNI-2004 symposium,** IGCAR, Kalpakkam, February 17-20, 2004

A Hybrid Charge Sensitive Preamplifier for Nuclear Spectroscopy Applications", V.D. Srivastava, P.K. Mukhopadhyay, Manoj Kumar Kori, Rakesh Mall and S.K. Sharma, **NSNI-2004 symposium,** IGCAR, Kalpakkam, February17-20, 2004

Hex Fast Amplifier and Quad Timing Filter Amplifier Based on Hybrid Fast Pulse Amplifier, Prafulla Satish, P.K. Mukhopadhyay and G.Joshi, **NSNI-2004 symposium,** IGCAR, Kalpakkam, February 17-20, 2004

P.K. Mukhopadhyay <pkmuk@barc.gov.in>

■ PHAST PC-MCA

Designed around a 100 MHz 8 k Wilkinson type ADC this incorporates spectrum stabilization facility suitable for low count rate long duration experiments. The data processing software includes multiple peak analysis, energy calibration and isotope identification. This has been incorporated in the operating software of other MCA systems developed in BARC.

P.K. Mukhopadhyay <pkmuk@barc.gov.in>

■ MCA-2000

MCA-2000 is used for pulse height analysis in nuclear spectroscopy system. The MCA-2000 utilizes the high density of FPGA to integrate most of the digital logic circuitry on a single chip. It also utilizes low power analog devices (operational amplifiers, comparators, ADC, DAC etc.) to reduce the power consumption. Entire analog circuits work on ± 5V power supply only. It accepts input from a Spectroscopy Amplifier for Pulse Height Analysis and offers all features of a research grade stand alone 8K MCA.

The MCA-2000 hardware also enables the user to manipulate the acquired spectrum data through its software user interface menus like Spectrum Smoothing, Peak Search, Energy Calibration, Efficiency Calibration, and Isotope Identification, etc.

Some of the major technical features of the MCA-2000 are low power consumption (≈ 2 Watts), compact size, ease of handling and full compatibility with existing MCA-95 hardware and software.

MCA-2000 card can work along with a desktop PC with standard software as well as it can go with an embedded system consisting of a small CPU board like *Chameleon* board.

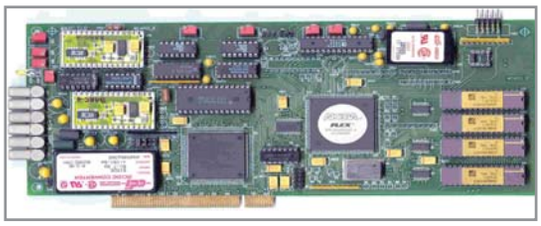
■ PCI-based Dual Input Multi Channel Analyzer, PCI_MCA-2D

P. P. Vaidya <ppvaidya@barc.gov.in>

This PCI-bus-based multi-channel analyzer is designed for high-resolution gamma spectroscopy. It accepts two analog inputs in the range 0–10 V with independent GATE and PUR signals for each channel. Designed with Field Programmable Gate Arrays, it also uses hybrid peak stretchers.

The analog inputs are multiplexed to a single ADC giving

6 microseconds conversion time per channel. It may work in two independent PHA modes or gated LIST mode for two parameter systems or in 2-D PHA mode. It has onboard memory for histogram. Live time is corrected by the Gedcke-Hale technique.



This card can be used as a single input MCA or 2 inputs LIST mode multi-parameter system. Normally for multi-parameter systems, bulky setups are required. This provides an elegant solution for small setups with only two parameters. There are four logic input signals available, their default purpose being GATE and PUR. But as they are fed to FPGA, they can be configured for any other coincidence logic function.

Anita Behare <abehere@barc.gov.in>

■ Compact 8K Multi-Channel Analyzer with USB Interface

A new, high-performance MCA (MCA-2005) having several advanced features has been recently developed. Some of them are with in-built hardware for *List* and *MCS* modes in addition to the standard *PHA* mode of operation, local spectrum memory

MCA-2005 Unit with Internal Circuit Board

and USB bus interface. The MCA uses an FPGA and it has the state of the art analog circuits for superior performance. The resolution is selectable from 256 channels to 8 K channels. It offers a DNL of $\pm$1% or better at 8K. It supports good input pulse rate (typically more than 100 KHz) without significant dead time penalty. The USB bus interface offers a truly universal and simple connectivity with almost any modern PC or Simputer for MCA data manipulation, control and display. The applications of

MCA System with Laptop PC

the MCA include energy spectroscopy, half-life analysis, and analysis of individual events, and it is a good fit for embedded and battery-operated instruments as well as for standard desktop instruments.

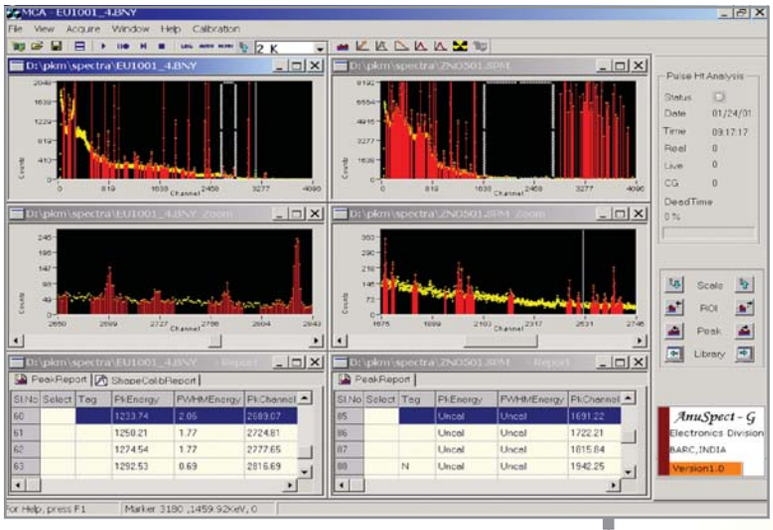
P. P. Vaidya <ppvaidya@barc.gov.in>

■ Portable Spectroscopy System (PSS)

The Portable Spectroscopy System (PSS) consists of a shaping amplifier followed by a 256 channel MCA. The pre-amplifier signals from detector can be directly coupled to this flexible PSS that can provide the High Voltage supply for NaI (Tl) detector or 24 V bias required by PIN diode based scintillation detector along with +/-12 V supply for pre-amplifiers. It includes a 6 V, 1.2 Ahr Sealed Battery allowing more than 5 hours of continuous operation with Spectrum display on the host Simputer.

The shaping circuits along with the MCA consume only 45 mA. A battery charger operated from any commercial 9 V adapter is included.

P. P. Vaidya <ppvaidya@barc.gov.in>



Simultaneous display of multiple spectra,
Multiple scaling options logarithmic, autoscaling
Automatic re-alignment of windows

AnuSpect-Software for Gamma Spectroscopy

AnuSpect, Radiation spectrometry system, an integrated nuclear data acquisition and analysis system with workbench approach is developed. Workbench architecture encourages exploratory approach and allows the user to plugin a variety of MCA hardware in local and remote configurations.

AnuSpect operates under MS windows platform (Windows 98,NT, 2000,XP). Present MCA hardware compatibility lists include PCA 95, PCA 2000, and PCI-MCA. Other features include: multiple live spectrum, mode of periodic measurements with automatic recording of spectra, simultaneous viewing of arbitrary number of spectra, scaling, peak report and ROI report, multiple file formats, automatic peak location and area determination, energy, peak shape and efficiency calibration, nuclide identification and activity estimation and exhaustive database for gammas.

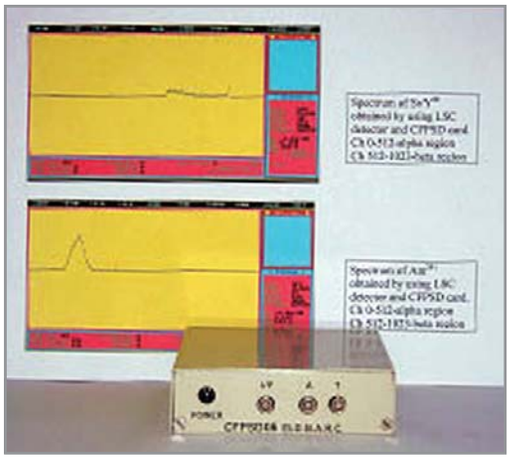
Its current applications include: Measurement and calibration of Bremsstrahlung X-ray, Energy Dispersive X-ray Fluorscence (EDXRF) techniques for analysis of various, Environmental Assessment, Waste Management, Fuel Reprocessing, Exploration and evaluation of mineral resources, Automatic analysis of rock samples for estimation of radio-elemental concentrations, Health and Safety related applications and Identification of radionuclides such as Np-239, Na-24, Mo-99, Cs-137, Cs-134 and Ce-144, estimate the activity in Heavy Water samples, fuel storage bay water samples and liquid effluent samples before discharge to ETP and identification of gaseous radionuclides such as Ar-41, Xe-133, I-131 and particulates in exhaust release through stack and other air samples. AnuSpect is also used for quality control in isotope (F18, C11, O15, N13) production for use in nuclear medicine.

Its installation base includes AMD, EAD, ECIL, FRD, IAD, IDD, RMC, RPAD, RSSD, Spectroscopy Division, TAPS, TIFR, and WMD Tarapur.

M. P. Diwakar <netsoft@barc.gov.in>

Compact Pulse Shape Discriminator (PSD)

Based on a new technique for pulse shape discrimination using the time dependence of constant fraction of radiation detector pulses, a low-cost high-performance stand-alone Compact Pulse Shape Discriminator *(CFPSD)* suitable for *nuclear particle identification* has been developed. CFPSD accepts pulses from output of charge sensitive preamplifier and discriminates between pulses based on their rise times.



The new CFPSD avoids use of bulky items such as delay lines amplifiers, constant fraction discriminators, time to amplitude converters etc, commonly used in commercially available pulse shape discriminators. The difficulties encountered in implementation of these circuits such as delay line reflections, exact determination of zero cross over etc. are also avoided. CFPSD is available as a compact portable

stand-alone unit and can be used with scintillation, gaseous and other detectors for nuclear particle identification.

P. P. Vaidya <ppvaidya@barc.gov.in>

■ Portable Sliding Pulse Generator

A portable battery-operated sliding pulse generator has been developed. It is useful for testing of portable MCAs and spectroscopy systems.

A high resolutin portable spectroscopy system, C.P. Kulkarni, P.P. Vaidya, M. Paulson, P.V. Bhatnagar, S.S. Pande and S. Padmini, **Proceedings of 15th National Symposium on Radiation Physics (NSRP-15),** BARC, Nov.12-14, 2003.

A very low background liquid scintillation counting system using active shielding techniques", Rajvinder Kaur, S.R. Jadhav, P. Shalakha, P.P. Vaidya, S.K. Kataria, **Proceedings of 15th National Symposium on Radiation Physics (NSRP-15),** BARC, Nov.12-14, 2003

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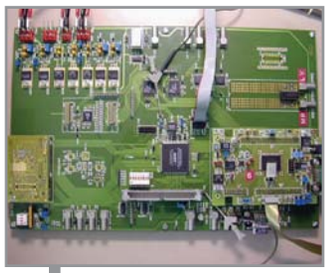
P. P. Vaidya <ppvaidya@barc.gov.in>

■ Front-end Electronics for CMS Preshower Readout System

The preshower is a detector system of CMS, which will utilize more than 4300 silicon strip detectors. Each of the 32 strips on each detector measures around 1.9 mm x 61 mm x 300 μm and has a capacitance of around 50 pF which imposes some strict requirements on the front-end electronics. The front-end electronics for the CMS preshower is designed and incorporated in a hybrid called PACE. The PACE is divided into two ASIC chips called Delta and PACEAM. Delta contains the front-end preamplifiers, shapers and calibration circuitry. PACEAM contains the analog memory (switched capacitor array), readout amplifiers, multiplexer plus the necessary control and interface logic.

Two PACE2a Test Boards Operating Synchronously in PSI Beam



PACE3 Test Board

BARC has developed the silicon strip detectors as well as actively participated in the development of stand-alone test bench to characterize different versions of PACE. The test bench is a PC-based system and consists of electronics board based on FPGA to generate LHC like fast timings along with necessary software. The PC-based menu-driven software allows the user to run on M16C microcomputer, various tasks like scanning the I^2C bus to detect the devices on it, writing or reading on I^2C bus, writing or reading from various registers in FPGA, handling delay lines or handling data from the FIFO (received from the PACE2).

M16C communicates with PC on RS232 and to PACE2 on I^2C. M16C, through its ports, provides the control signals, which are required for communication with FPGA.

S.P.Borkar <bsuhas@barc.gov.in>

■ Photon Counting Systems

Some of the instrumentation developed for accelerator projects is also useful to researches in laser/optical spectroscopy fields. The instrumentation needs in such areas could be fulfilled by enhancing the already developed instrumentation and developing fast photon counting instrumentation, Boxcar integrators, Gated photon counting systems, fast Multi-Channel Scaling (MCS) and Auxiliary support modules. Some modules were developed for individual requirements of the users, but continuous development has led them to be generic in nature.

Towards front-end instrumentation for Photon Counting, various voltage /current pulse pre-amplifiers with rise time 1-2 ns, gain, and dynamic range from 1 to 2/5 V have been developed. These have the facility to adjust gain. These amplifiers are NIM modules or small modules located on top of the detectors. The amplifier modules are associated with quad discriminators (CFD versions also) with pulse pair resolution of 10 nS in NIM/CAMAC.

Counters /MCS are also developed. Single or quad 100/50 MHz counters are available as NIM / CAMAC modules. An integrated photon counting module consisting of amplifier, discriminator, pre-scalar, counter, rate-meter integrated photon counting is developed and supplied to various users.

(V.B. Chandratre <eld03@barc.gov.in>

■ Distance Learning (DL) Modules on Troubleshooting of Nuclear Instruments

BARC has entered into a Contract Research Project (CRP) No. 11835/R0, "Development of Distance Learning (DL) Modules on troubleshooting of Nuclear Instruments in India". Along with other organizations, BARC has been given the responsibility of developing these tools for RIA system. Under this program, the introductory document comprising theory needed for understanding the RIA equipment and their performance, RIA basis, Radiation principles and Radiation detection, Scintillation Detectors, Common electronic circuit of power supplies, transformer rectifier filter, Regulating circuits, Protection circuits, Preamplifier circuits, Single Channel Analyzers, Scaler/ Counter have been prepared and submitted to IAEA in the first year. The present document addresses Physical inspection, Counter, Timer, Rate-meter, Amplifier (Functionality test with QC) , Energy Calibration (Window setting v/s Energy) , Resolution (FWHM) v/s Energy, Statistical Performance , Background Measurements, Programming of virtual RIA Instrumentation using LabView for Simulation of Counting Chain, Fault Identification and Test Procedures .

G. D. Jindal <jindal@barc.gov.in>,
T.S.Ananthakrishnan
<anant@barc.gov.in>

4.3 HEALTH PHYSICS INSTRUMENTATION

■ Gamma Low Range Monitor

BARC developed a Gamma Low Range Monitor (Model: GL) to monitor low range gamma background activity in rooms, chambers etc. It incorporates GM

tube as detector and can indicate Gamma activity over 5 decades from 0.1 mR per hour to 10 R per hour and gives output in the form of standard 4 to 20 mA range. This makes it easy to interface with present data acquisition systems. Its compact size ensures optimum space utilization. Circuit for missing pulse detector is in built in the GL. It gives an output that can be connected to an audio or visual indicator as per user requirement.

R.K.Jakati <rkjakati@barc.gov.in>

High Range Gamma Monitor

High range Gamma Monitors (model: GH) developed at BARC measure dose in the range 10 mR/hr to 2000 R/hr. It is used to measure the ambient gamma radiation level at various locations of the operating plant. Once the normal ambient levels are known, any abnormal operation of the plant is detected by one-decade change in the dose rate level. Normal ambient levels are function of location, radioactive sources, shielding structures etc. 4-20 mA Output signals and counter failure signals from these monitors are connected to Radiation Data Acquisition System.

R.K.Jakati <rkjakati@barc.gov.in>

Neutron Monitor

Neutron Monitors measure the neutron flux in intermediate energy range of reactor environment. The monitor covers the flux range from less than 5 nV to more than 5000 nV. The 4-20 mA-output signal and detector failure output signal of this monitor are connected to RADAS for data augment purpose. Low voltage power required for these sensors is drawn from the common power supplies located in RADAS. The sensor consists of a BF3 counter placed along the central axis of a cylindrical moderator made from a paraffin block of size 12 cm diameter and 10 cm length and surrounded with a cadmium shield to stop thermal response of the BF3 counter. This makes the sensor compact and light weight.

R.K.Jakati <rkjakati@barc.gov.in>

Contamination Monitor

The Contamination Monitor is used mainly for measuring Beta contamination on any surface like a vehicle platform or even a person's body. It uses End-window GM tube with sensitivity of 25 cps per MPL of contamination as a detector for beta radiation.

It operates in 4 ranges and indicates the contamination in terms of Counts Per Second (CPS) on a front panel meter. Facility to set up alarm limit is available on front panel. Indication of counter failure (visual form) and alarm (audio visual form) is also provided.

R.K.Jakati <rkjakati@barc.gov.in>

Skin Absorbed Dose Monitor

Dose rates to the skin from beta sources are many times under estimated or some time even neglected. However, one milli curie of Sr 90 plane source produces a contact dose of few thousand Rad/Hr to the skin below the epidermis. Many of the existing radiation monitors fail to measure the surface dose rate from the extended beta source. To solve this difficulty suitable monitor using plastic scintillator and photomultiplier has been developed. The purpose of the instrument is to monitor beta radiation, during the servicing and maintenance of coolant pipeline. Any leakage in pipeline may spread beta activity over the surface of the pipeline,

hence before starting any maintenance job over a pipeline the surface area is scanned by this portable probe. Once the beta dose rate is found within reasonable rate the permission is granted for maintenance. A polythene cap is also provided with the probe, which can be used to measure only gamma dose rate thus eliminating beta dose rate.

R.K.Jakati <rkjakati@barc.gov.in>

Water Activity Monitor

Water activity Monitor is developed to detect the Steam generator tube failure. It measures the Gamma activity in the steam after condensing the steam at a pressure of 30 Kg/Sq.cm. The activity of the condensed liquid is measured. Steam from each steam generator is condensed and measured separately so as to identify the leaky generator.

R.K.Jakati <rkjakati@barc.gov.in>

Beta Aerosols and Beta Gas Monitor

Air present in area within the containment of the operating plant may be active due to the presence of suspended radioactive particles and gases. Aerosol are trapped on filter paper and monitored. 5 Ltr. Chamber is used for gas monitoring. Plastic scintillator sensitive to beta activity produces scintillations, which are converted into electronic pulses using photo-multiplier tube. The range of the activity is between 10^{-10} to 10^{-6} curies/litre.

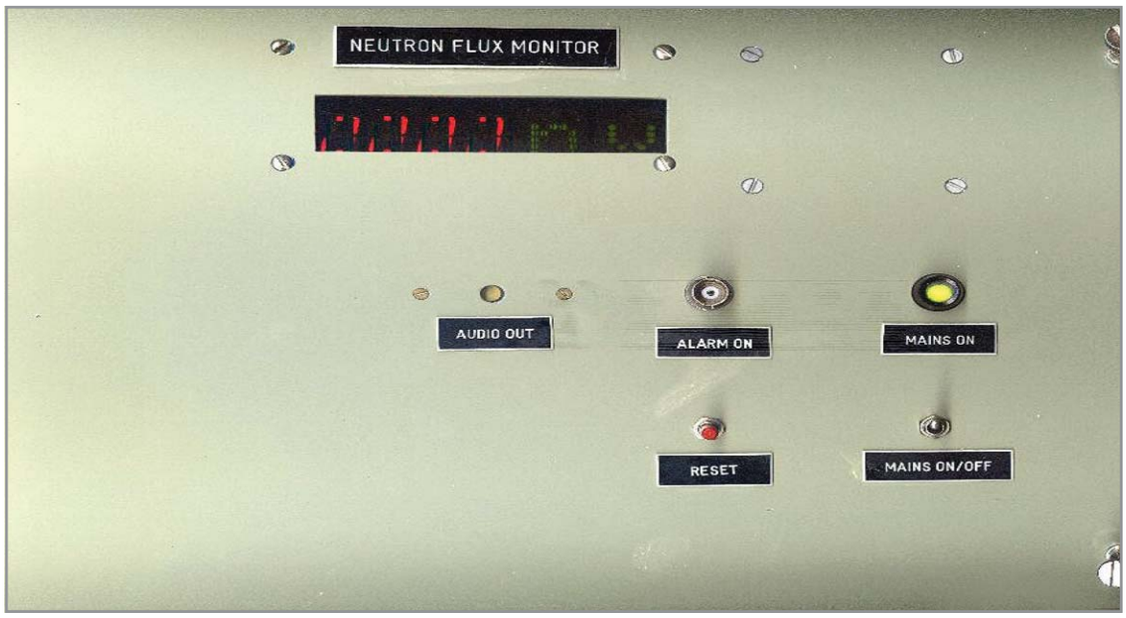
R.K.Jakati <rkjakati@barc.gov.in>

Neutron REM Monitor

A Neutron REM Monitor based on the classic Anderson Braun technique (with state-of-the-art electronic circuits) has been developed. The sensitivity of the monitor is 4.35 cps/mRem. It has been tested for 0.025 ev to 4.5 Mev neutron strength and

the results closely follow the ICRP 60 REM response curve. Both, mains-operated and battery-operated (portable) REM monitors have been developed. The mains operated unit is intended for continuous monitoring of dose levels of neutron radiation at reactors and in other locations where a permanent dose monitoring system is required. The battery operated unit serves the purpose of conducting routine surveys.

R.K.Jakati <rkjakati@barc.gov.in>



Neutron Flux Monitor

It is a mains-operated unit using detector (BF3 counter LND make) and moderator (HDPE) within the system. It is sensitive to neutron energies from few eV to 10 MeV and flux indication is independent of energy of radiation within its flux Range 2 nV to 20,000 nV. It comprises of a charge sensitive pre-amp with 6.06 mV/MeV sensitivity Bias the detector using HV of 1100 V, 40 mV ripple. It supports RS 485 & optional Ethernet connectivity to central data acquisition system.

R.K.Jakati <rkjakati@barc.gov.in>

Pulsed X-Ray Monitor

These monitors are located at different places to ensure personnel radiological safety in accelerator environment. The instrument continuously monitors the radiation levels at specified occupancy location and provides an alarm if preset level is exceeded. The detector used in these monitors is a pressurized cylindrical ionization chamber. The energy response is from 100 KeV to 1.25 MeV. Argon is used as a filling gas at pressure 160 psi. The output is provided in the form of 4-20 mA.

R.K.Jakati <rkjakati@barc.gov.in>

Area Gamma Monitor

Area gamma monitors are used for continuous monitoring of gamma radiation levels in the environment. These are fixed type, stand-alone and self-contained units, which can be networked into a networked system of multiple monitors in a plant via RS232, RS485 or Ethernet port.

Compact Neutron Flux Monito, V. Madhavi, P.R. Phatak, C. Bahadur, A.K. Bayala, R.K. Jakati,(V. Sathian, RSSD), **Proceedings of 15th National Symposium on Radiation Physics (NSRP-15),** BARC Nov.12-14, 2003

Smart Neutron REM monitor developments, V. Madhavi, P.R. Phatak, A.K. Bayala, R.K. Jakati, U.V. Phadnis(RSSD), **Proceedings of 15th National Symposium on Radiation Physics (NSRP-15)** BARC, Nov.12-14, 2003

Smart Radiation Monitors Prototype Development with Standardized Boards, P.R. Phatak, P.Y. Bansode, R.K. Jakati and S.K. Kataria, **Proceedings of 15th National Symposium on Radiation Physics (NSRP-15),** BARC Nov.12-14, 2003

R.K.Jakati <rkjakati@barc.gov.in>

5. COMPUTERS AND SOFTWARE

INTRODUCTION

BARC is a premier research organization working on the development, demonstration and deployment of technologies related to nuclear reactors, nuclear fuel cycle, isotopes and radiation applications. It carries out inter-disciplinary and multi-disciplinary R&D activities covering a wide range of disciplines in physical sciences, chemical sciences, biological sciences and engineering. Expertise at BARC covers the entire spectrum of science and technology. Scientists and engineers working on advanced R&D projects at BARC are extensively using computers for meeting their requirements of supercomputing, general scientific computing, scientific visualization, information processing and information exchange.

In order that BARC scientists and engineers carry out their frontline R&D work effectively and remain internationally competitive, it is extremely important that the computing and communication facilities available at BARC are not only enough to meet the ever-growing requirements but also match the latest facilities available abroad at large R&D institutes. The major objective of the Computer Division is to carry out R&D in advanced computing with the sole purpose of meeting the above requirements of BARC Scientists and Engineers. Our major efforts have been essentially in developing systems, software and applications based on open source and off-the-shelf commodity components. Thus, our efforts have been directed towards making available a world class secure computing infrastructure to our Research Community in particular and other national institutes of the country in general, at affordable prices.

It is important to build great infrastructure and share it. It is even more important to share our infrastructure with whom we want to share and to protect our infrastructure from misuse by unauthorized agencies. This has opened up areas of research in security both in physical and cyber domains. Thus, to provide cutting edge compute infrastructure, we not only need to continually develop very high-end computers and associated technologies but also will have to work on its security aspects. In addition to the aforementioned fields, Computer Division, BARC is engaged in frontline research in many areas of Computer Science like Advanced Computing, Visualization, Information Security, Networks, Information/Knowledge Systems, Image processing & Vision Systems, Computer based Instruments & Control Systems and many more. In this chapter, we present an overview of the salient achievements during the last few years.

5.1 ADVANCED COMPUTING

Of late, very high-resolution models are being studied to realistically represent and investigate physical phenomenan. Simulations of such phenomenan require huge computational power. We have exploited parallel processing techniques to provide this power. By and large, the amount of data generated by these simulations will be very huge. This data needs to be stored and retrieved at a faster pace as and when needed. This requirement has been met by developing parallel file systems. However, the basic purpose of computation is to gain 'insight' into a problem one is trying to investigate and not generate mere numbers. To achieve this, one needs to represent the data generated in a visual form. This has been realized by developing post processor and visualization packages.

As the amount of data to be visualized becomes very large, the final rendered image on a regular 21" monitor will not have contributions from many of the data elements simply because their projected size on the monitor will be less than the size of a pixel. Thus we may lose representations from vital data. This loss will become more prominent when we try to investigate continuously evolving systems. To alleviate this problem, a large, scalable tiled display system based on 'parallel rendering' technique has been designed. In this, one can visualize the phenomenon on a large display made from tiles of displays put together and each such display segment driven by a separate processor. Thus, we have exploited parallel processing to deliver very huge computational power, very fast & large storage and large tiled display. In essence, parallel processing has been exploited to provide a complete integrated solution for scientific computation, where one can compute, visualize and store.

As is evident from the above discussions, a complete simulation needs a large number of resources, which may not be present with a single laboratory/ Institute. But, they may be collectively available across different administrative domains or even across institutions, which are geographically distant from each other. Currently we are developing solutions based on Grid Technology, which enables sharing of resources across such domains.

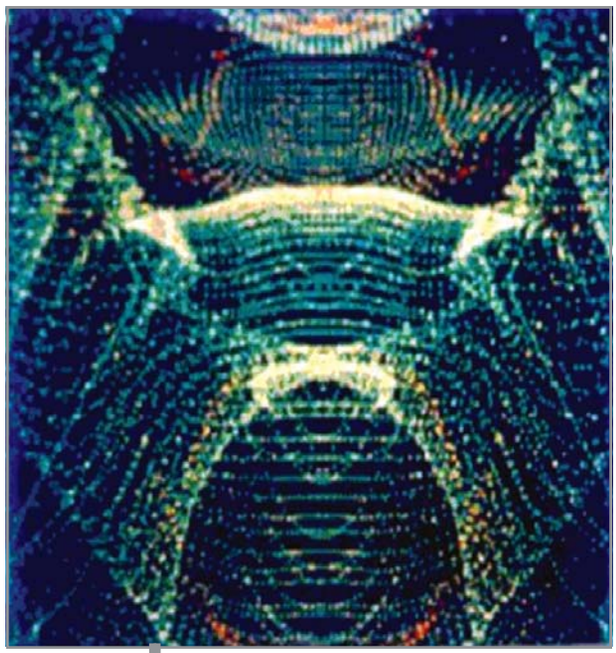
■ High Performance Computers

Recently, BARC has achieved another very significant milestone in the field of supercomputers by developing a **128 processor** ANUPAM supercomputer. The computing power of this supercomputer is observed to be **365 Giga Floating Point Operations Per Second (GFLOPS)** on High Performance Linpack benchmark program. This computer is about five times faster than the 64-node supercomputer developed earlier, in July 2002. BARC is actively pursuing development of supercomputer systems based on parallel processing techniques, primarily, for meeting the in-house requirements of solving very large computational problems for various scientific and engineering applications, since 1991. So far BARC has developed sixteen different models of the ANUPAM series of parallel supercomputers using a variety of processors as compute nodes and various technologies for interconnection networks.

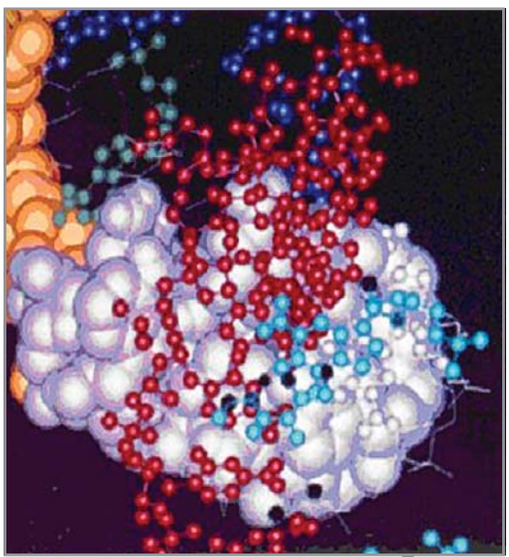
The Anupam-Xeon/128 Processor Super Computer

The 128-processor ANUPAM supercomputer is built using 64 dual Xeon servers as compute nodes in a cluster, interconnected by a high-speed communication network. Each server is based on dual Xeon, 2.4 GHz processors and has 2 GB memory and 40 GB hard disk. The inter-communication network is designed using Scalable Coherent Interface (SCI), with a very high node-to-node communication speed of 300 megabytes per second and a very low latency of 3.5 microseconds. The open source Linux operating system is used on each parallel processing node. For implementing parallel processing applications on the ANUPAM system standard Message Passing Interface (MPI) is available. An advanced Parallel File System is implemented on ANUPAM supercomputers for efficiently processing supercomputing jobs with large Input/Output. Further, the system is equipped with Auto-installers for the quick installation of the operating system and other software packages on all the nodes of the system from a central server. The system also has self-correcting monitor with features such as, detecting and isolating faulty nodes, stopping the execution on the run-away nodes and monitoring the operation of various other services.

The supercomputers at BARC are being used for solving very large computational problems in the fields of Condensed Matter Physics Simulations, Electronics Structures and Molecular Dynamics Simulations, Radiation Chemistry, Atmospheric Chemistry, Finite Element Analysis of non-linear problems, Computational Fluid Dynamics, Radiation Hydrodynamics, Crystal Structure Analysis, Neutron Transport Computations, Gamma Ray Simulations, Electromagnetic Plasma Simulations, First Principle Electronic Structure Computations, Structural Analysis and Laser-Atom Interactions. Typical in house applications have been depicted in the diagrams given here.



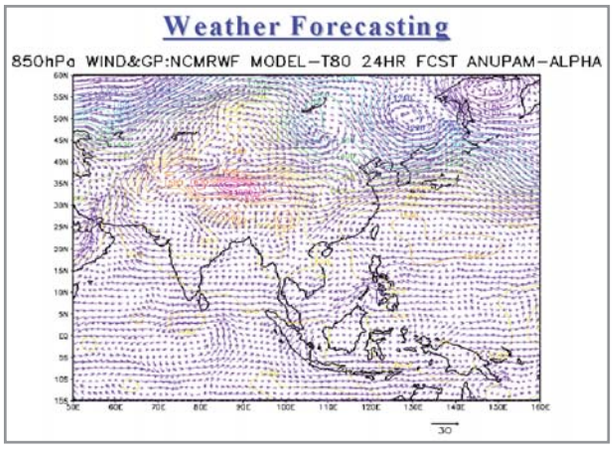
Plasma Computations



Protein Molecule Structure

In addition to the supercomputers at BARC, a number of ANUPAM series of supercomputers have been commissioned at various leading institutes in the country such as Aeronautical Development Agency (ADA) Bangalore, Vikram Sarabhai Space Centre, Thiruvananthapuram, National Centre for Medium Range Weather Forecasting (NCMRWF) New Delhi, Nuclear Power Corporation Mumbai, IIT Mumbai, IIT Kanpur, UDCT Mumbai, SNDT Mumbai etc.

In all, there are about 35 Anupam Installations all over the country. Aeronautical Development Agency has been using ANUPAM series of supercomputers for solving Computational Fluid Dynamics problems related to the airflow through the intake ducts of aircrafts. NCMRWF, Delhi has been using ANUPAM-Alpha supercomputer for regular processing of computational problems for weather forecasting since December 1999.

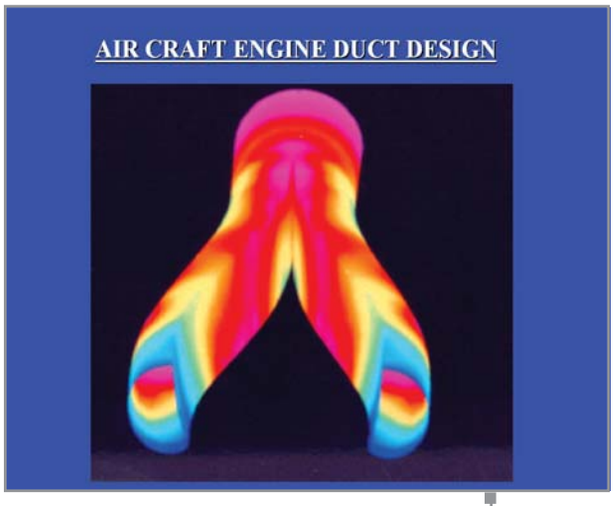


Performance Evaluation of Gigabit Ethernet and SCI in Linux Cluster K.Rajesh, Digamber Sonvane **First International Conference on Distributed Computing and Internet Technology,** Bhubaneswar, Dec-2004

Performance Analysis of Parallel File System for I/O Load Balancing in DistributedApplications, S.Deepalakashmi, K.Baswaraj, S.S.S.P.Rao, B.S.Jagdish, D.D.Sonavane, P.S.Dhekne, H.K.Kaura **The 2003 International Conference & Distributed Processing Techniques and Applications, PDPTA'03,** June 2003, Las Vegas, USA

ANUPAM-ALPHA Parallel Computer for operational Weather Forcasting, B.S.Jagadeesh, K.Rajesh, R.S.Mundada, Phoolchand, P.S.Dhekne and H.K.Kaura, **HPC Asia,** Beijing, 2000 , IEEE Computer Society Press

Benchmarking of the BPPS System with A 3D Explicit Navier Stokes code 'Vasbi' for a Non Diffusing S-Duct Biju Uthup, K.Rajesh, S.M.Deshpande **Supercomputing for Scientific Visualization,** BARC, Feb 1994

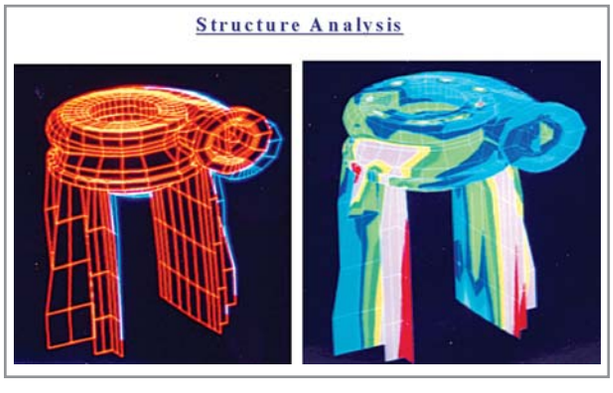


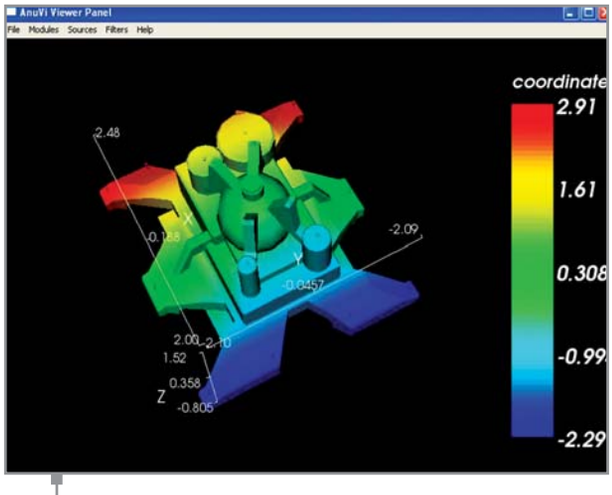
CFD Analysis, ADA, Bangalore

Visualization

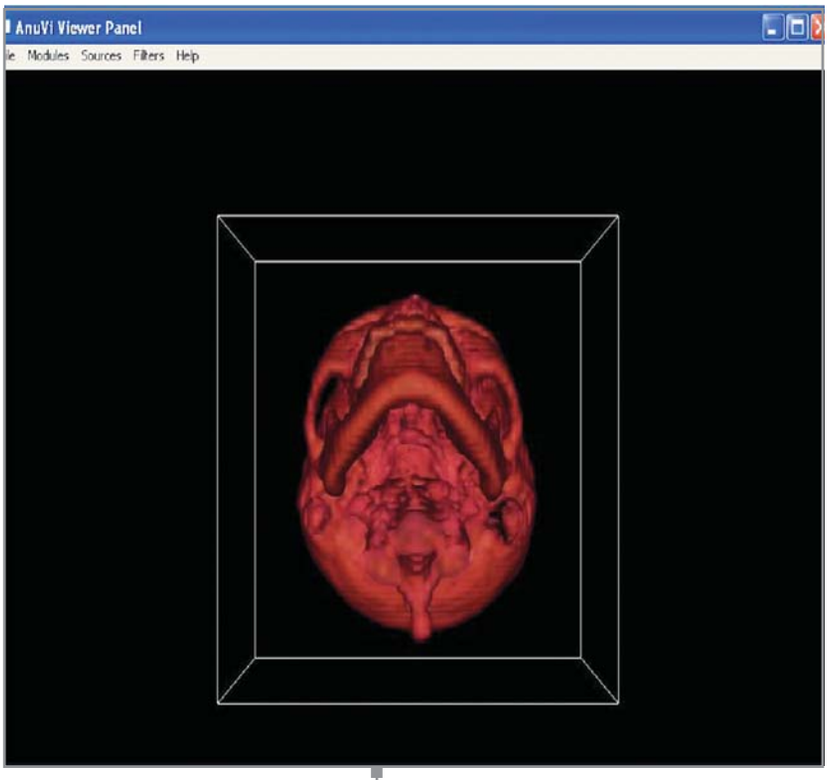
AnuVi: A Scientific Visualization Framework

A general-purpose post processor package, which enables scientists to visualize data without having to bother about the format differences that exist amongst various commercially available packages, has been the long-standing need of the scientific community in BARC. Computer Division, BARC, has developed "Anuvi", a cross platform 3D scientific visualization and interrogation framework. It provides animation, extraction and derivation over many data components using advanced graphical features (including shading, contouring, lighting and transparency effects). It is an engineering tool, which allows one to examine the voluminous data generated by scientific computations.





Visualization of CFD Analysis of a Space Station



Volume Rendered Image of Human Brain

A few of the important features of this package are:

- The package handles structured (uniform rectilinear, non-uniform rectilinear, and curvilinear grids), unstructured, polygonal and image data.

- All processing operations (filters) produce datasets. This allows the user to further process the result of every operation. For example, the user can extract a cut surface, reduce the number of points on this surface by masking, or apply glyphs (for example, vector arrows) to the result.

- Contours and isosurfaces can be extracted from all data types using scalars or vector components. The results can be colored by any other variable or processed further.

- When required, structured data contours/isosurfaces are extracted with fast and efficient algorithms, which make use of the special data layout.

- Vector fields can be inspected by applying glyphs (arrows, cones, lines, spheres, and various 2D glyphs) to the points in a dataset. The glyphs can be scaled by scalars, vector component or vector magnitude and can be oriented using a vector field.

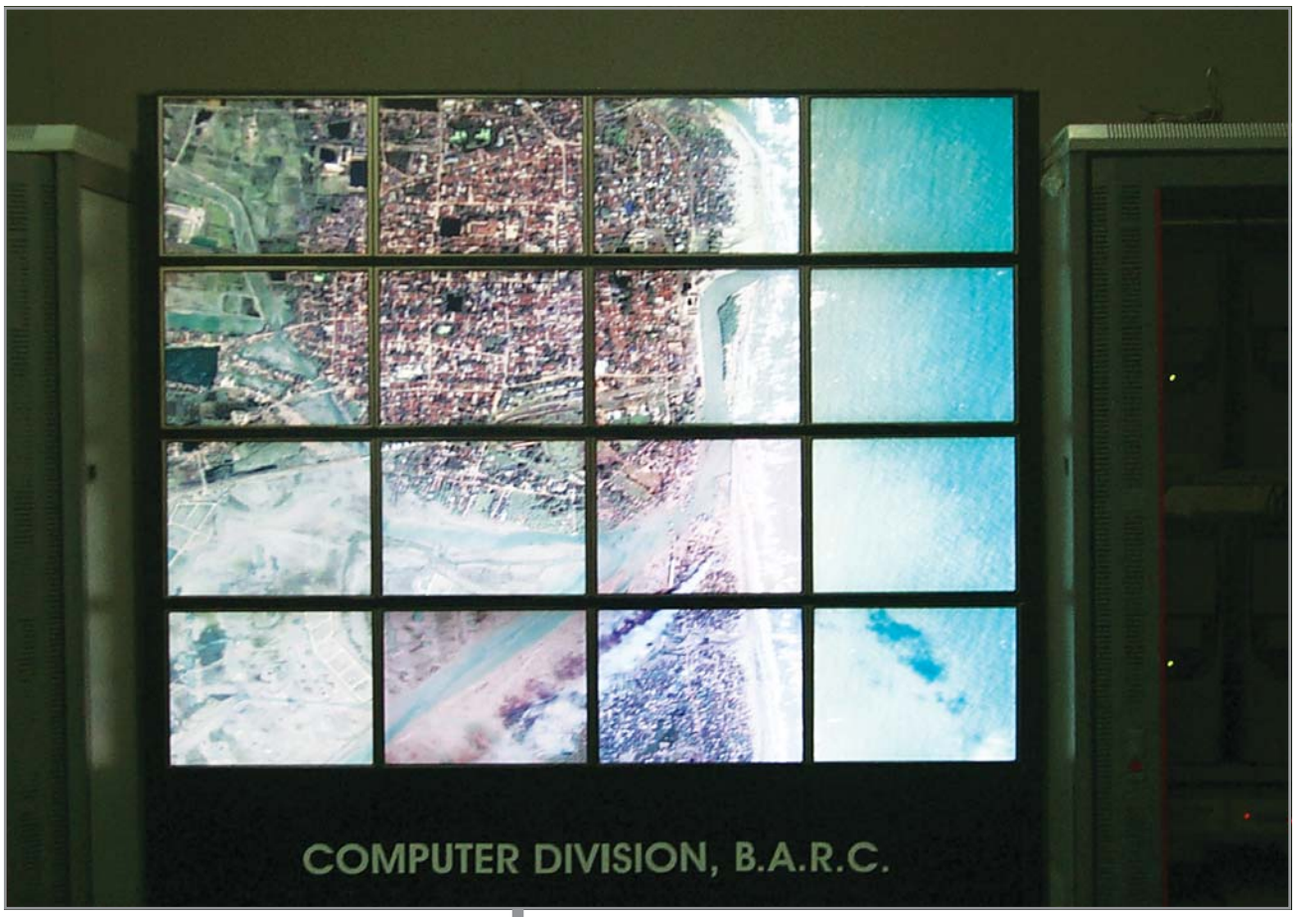
- A sub-region of a dataset can be extracted by cutting or clipping with an arbitrary plane (all data types), specifying a threshold criterion to exclude cells (all data types).

- Streamlines can be generated using constant step or adaptive integrators. The results can be displayed as points, lines, and can be processed by a multitude of filters.

- The points in a dataset can be warped (displaced) with scalars (given a user defined displacement vector) or with vectors (unavailable for non-linear rectilinear grids).

- Data can be probed at a point or along a line or along a plane. The results are displayed either graphically or as text and can be exported for further analysis.

AnuVi provides many other data sources and filters by default (triangulation, reflection, decimation, transform,



Post-Tsunami: Nagappattinam, India (Lat: 10.7906° N Lon: 79.8428° E)

contouring...) and any VTK filter can be added by writing python code (VTK provides hundreds of sources and filters).

Scalable Graphics System

Computer Division, BARC has developed a parallel visual environment by combining many LCD displays in a tiled fashion and each of these is driven by a separate processor. A master processor does the control and coordination of placing the object portions in different tiles. The processing and rendering of the data corresponding to a given tile is done by the processor along with the graphics accelerator card attached to it. Thus, one has a resolution of 5120 X 4096 (20 million pixels and a physical dimension of the display as 145cms X 120cms for the 4X4 tiled display) and by exploiting parallel processing techniques, realistic animation rates (20 frames/Sec.) for this large display has been achieved. This parallel visualization environment will be of a great utility value to any research institute and will go a long way in visualizing high resolution, voluminous data in animated form and help in studying continuously evolving physical phenomenan. (The picture depicts one-meter resolution image taken by Space Imaging's IKONOS satellite on Dec. 29, 2004 — after the devastating tsunami hit. One can clearly see the way sea has entered into the land).

Virtual Reality: Heading Towards PC cluster, Dinesh M.Sarode, S.K. Bose, Venkata P.P.K, P.S. Dhekne, H.K. Kaura, **Proceedings of IICT Diamond Jubilee Seminar on Virtual Reality in Pursuit side of Excellence held at IICT,** Hyderabad during June 4-5,2004

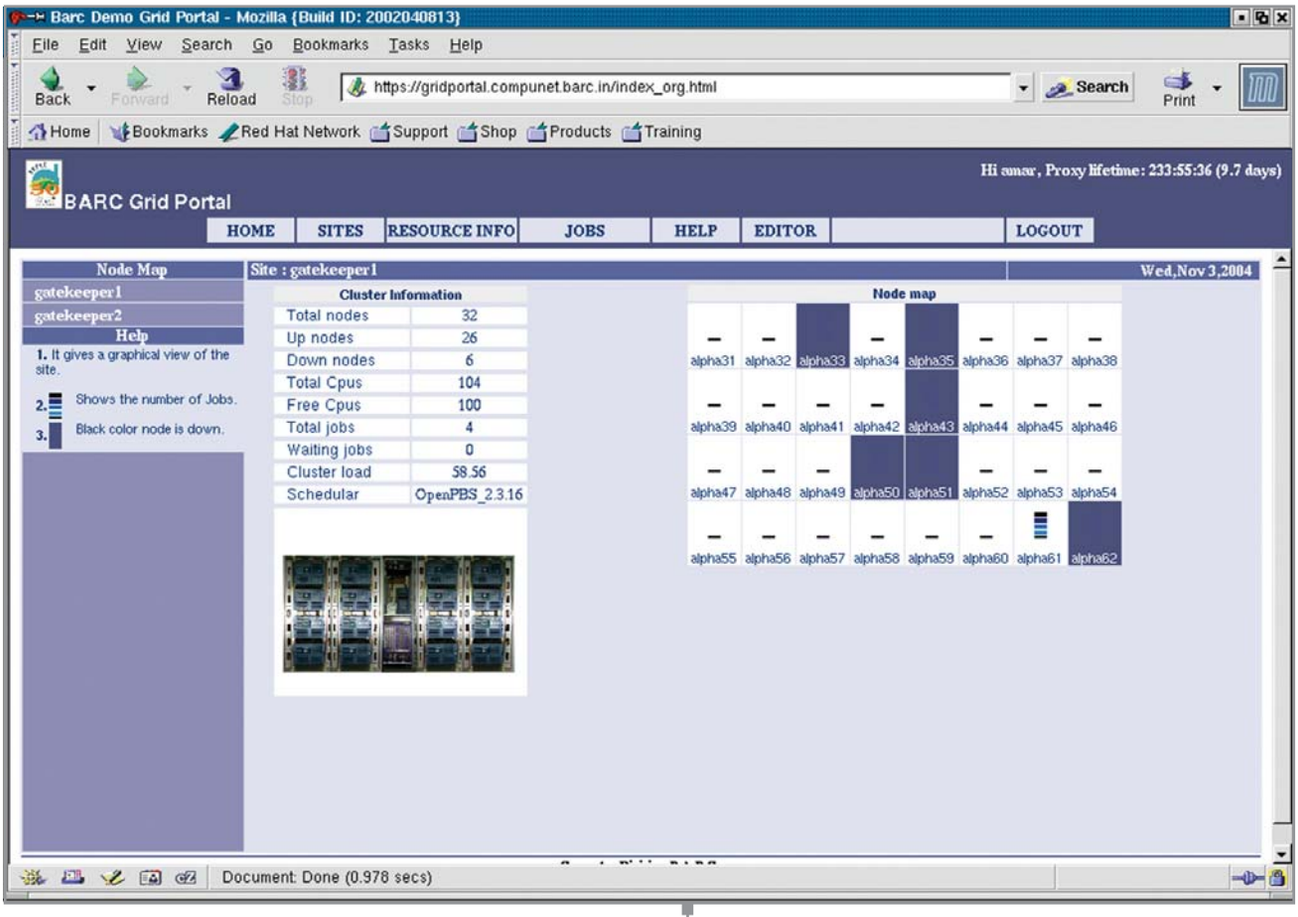
Virtual Reality – Applications and Technology, S.K. Bose, Dinesh M . Sarode and P.S. Dhekne in **Proceedings of DAE vision of information Exchange held at VECC.** Kolkata during Jan 30-31, 2003

Grid Computing

Grid Computing enables the sharing, selection and aggregation of a wide variety of geographically distributed computational resources (such as supercomputers, compute clusters, storage systems) and presents them as a single, unified resource for solving large-scale compute and data intensive computing applications.

International Collaboration in Grid Computing

European Organization for Nuclear Research (CERN) is building Large Hadron Collider (LHC), the largest accelerator in the world, for searching Higgs particle leading to the understanding the origin of masses of fundamental particles and unification of fundamental forces of nature. Four large experiments, ALICE, ATLAS, CMS and LHCb, are being planned for the detection of subsidiary particles generated during the collision of the proton beams. Each collision is expected to generate up to 2000 subsidiary particles, which will be observed through 180,000 channels. At a collision rate of 40 MHz, the expected data generation rate out of the experiments is about 7- 8 Giga Bytes per second, amounting to 8-10 Petabytes (1000,000 Gigabytes) of data generated in a year of experiment time.



Grid Portal Depicting Resource Information

A prototype Computational Grid has been developed by using open technologies like Globus toolkit, OpenPBS, OpenAFS, Ganglia etc. A web-based Grid Portal which frees the users from the burden of writing scripts to do authentication, resource discovery, job submission, job monitoring and result collection has been developed. Users are not required to install Grid middleware on their server to access grid services. Users need only web-browser to access all the grid services offered by Computational grid.

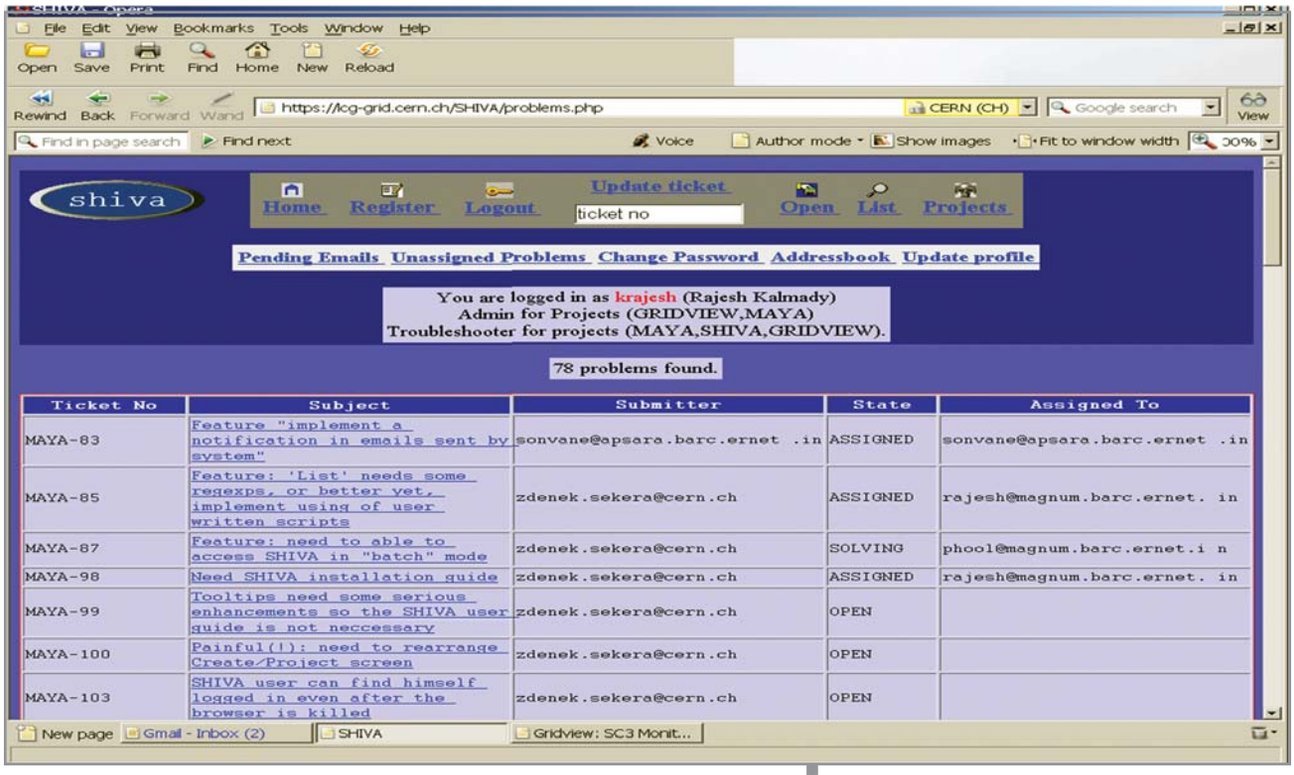
The extraction of results from the LHC experiments will present a number of challenges in terms of computing, due to the unprecedented complexity and rates of the data, the length of time of the programme and the large (Presently 1800 Physicists, 150 Institutes, 32 Countries) geographically distributed scientific communities that will coherently need to operate on these data. The computing challenges in the LHC lie in the real time storage of the huge amount of data (peta bytes), huge computational power(20-30 tera flops), re-construction of tracks of particles released during collision and computational simulation for physics experiments.

Clustering a large number of the processors has been the standard practice being followed for the past several years for meeting the very large computational requirements beyond the capacity of the available processors.

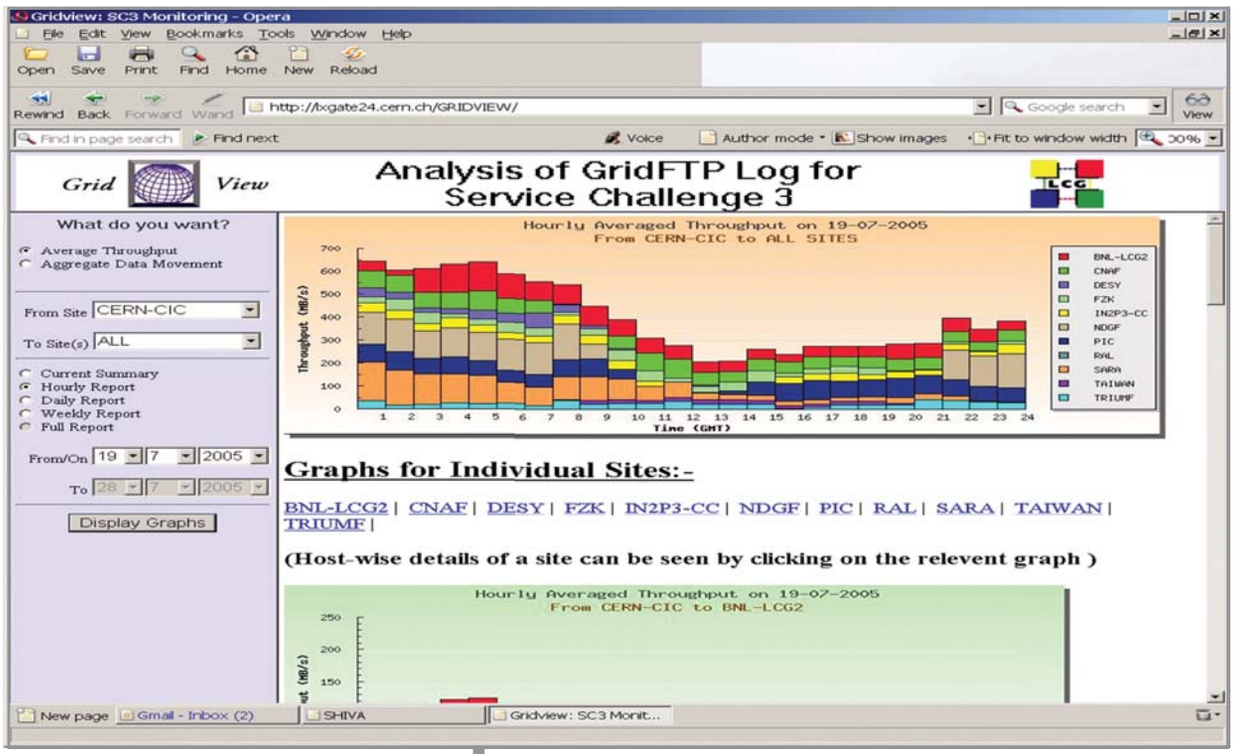
However, clustering beyond a few hundred processors is extremely expensive. In addition, it has many problems due the huge requirement of space, electricity and air-conditioning thus, making it beyond the capacity of any single large laboratory.

CERN is planning to meet the computing challenge of LHC by using Grid Computing technology with the objective of exploiting widely dispersed Large National Computing facilities located in various countries in a hierarchical fashion by categorizing these centres into tier1,tier2 and tier3 centres based on the compute, storage and archival infrastructure and connectivity to CERN. In additional to hardware, this involves a huge software development effort to present these resources as a single resource to users in a seamless fashion. **DAE and CERN have signed a Protocol Agreement for Grid Software Development on a DATA Grid called LCG for LHC data analysis, in the framework of development of computing and computational Grid Technology.** Under this collaborative effort Computer Division, BARC has developed and deployed the following projects successfully in collaboration with IT Division, CERN:

A software tool was required, which would efficiently keep track of problems in various activities of the LCG project.



Problem Tracking System - SHIVA



Snapshot of GRIDVIEW

The tool would enable users to submit problems, route the problems to assigned troubleshooters, keep track of the status of the problems and record the solutions. Computer Division, BARC took up this project and developed the problem tracking system, named SHIVA.

SHIVA is a software tool for implementing problem tracking systems for software projects. Though designed especially for software projects, it can also be used for tracking issues (bugs, defects, feature requests and tasks) in any other type of projects. It features bug side reporting, classification, assignment, sorting, searching, access control, email submission, attachments, address book, user profile, email notification, reminder mechanism, Web services and so on. It supports multiple projects, versions, self-registration, subscription, system administration, project administration, spam management etc. It can be used for beta test bug reporting, user support, or helpdesk system.

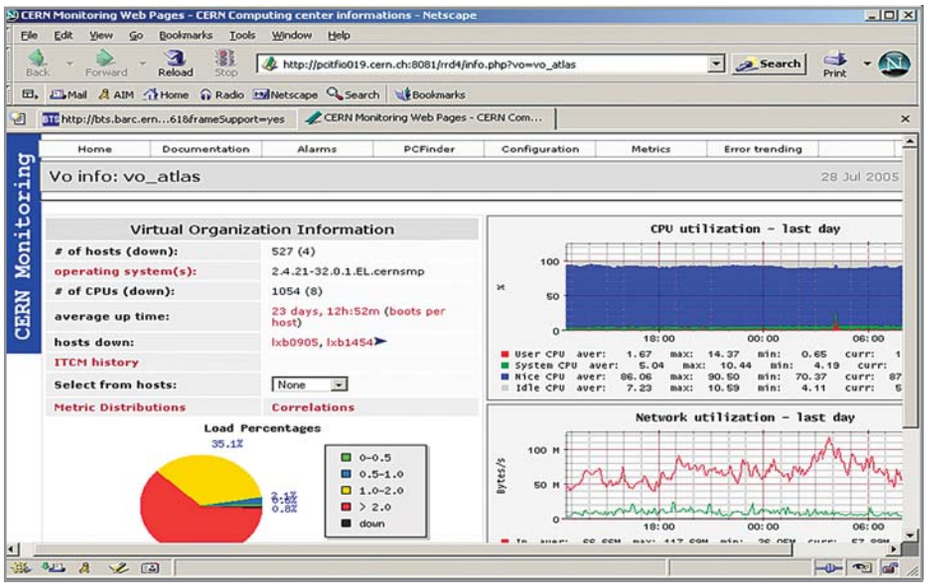
This system was accepted by the LCG community and is now being used as the problem tracking system for all LCG deployment activities in CERN.

Visualization Tool for LCG – GRIDVIEW

Various performance and functional metrics are monitored by different monitoring tools at various sites of the LCG. These performance and functional metrics include parameters such as availability of compute resources, data resources, status of jobs, status of various services, network throughput, file transfer logs and so on. In order to visualize the grid as a whole, there is a need for a tool which will display a dash-board for the entire grid indicating its status, collect the monitored data from the various systems into a common database, analyze, summarize and display it graphical form. **The first version of this tool is now commissioned at CERN** and is being used by the grid community to visualize the results of the Service Challenge tests being conducted in the LCG.

ELFMS - A Fabric Management Suite for Grid

Extra Large Fabric Monitoring System (ELFMS) is a fully modular and interoperating framework to manage a large, heterogeneous environment in several dimensions. First of all, in terms of functionality and size, it includes large general-purpose batch



tracks hardware workflows in the CERN Computer Centre and allows equipment to be visualized and easily located. Computer Division, BARC is involved in development of CCTracker utility on LEAF.

Quattor is a system administration toolkit providing a powerful, portable and modular tool suite for the automated installation, configuration and management of clusters and farms running UNIX derivates like Linux and Solaris. Computer Division, BARC is involved in testing and trouble shooting of various modules on Quattor. We are currently managing one of our clusters using Quattor.

and interactive server farms, disk and tape servers, database and web servers, etc. Also, various generations of hardware co-exist leading to a multiplicity of setups for example in terms of CPU types, memory and disk sizes. ELFMS consists of three major tools: Quattor, Lemon and LEAF. Computer Division BARC is collaborating with CERN IT Division in developing and providing technical support for these three tools. **Lemon** is a server/client based monitoring system. On every monitored node, a monitoring agent launches and communicates using a push/pull protocol with sensors, which are responsible for retrieving monitoring information. The extracted samples are stored on a local cache and forwarded to a central Measurement Repository. Sensors can collect information on behalf of remote entities like switches or power supplies. The Measurement Repository can interface to a relational database or a flat-file backend for storing the received samples, and can be queries via SOAP based API. Computer Division, BARC has developed several sensors like Sensor_Proc_Gid (to identify virtual clusters in server farm), Sensor Enhanced (collects various metrics like no. of processes, file_checksum, parseLogFile etc.), Sensor Alarm (correlates metric values and generate alarm and take action) etc. We are also responsible for developing and providing technical support for this monitoring agent.

LEAF is **LHC-Era Automated Fabric**. It consists of a **State Management System (SMS),** which enables high-level commands to be issued to sets of quattor-managed nodes, and a **Hardware Management System (HMS),** which manages and

5.2 SECURITY SYSTEMS

■ Security Systems (Physical Domain)

BARC being a nuclear research organization, has reasonable level of security threat of various types and fear of theft of nuclear materials, necessitating robust physical protection & control of various facilities.

Computer Division, has been proactively developing and implementing Physical Protection Systems keeping in view the threat perceptions and to aid the BARC security staff with effective implementation of modern IT gadgets. This warrants for the usage of variety of electronic and computer based surveillance systems. The model adopted is 24x7 monitoring of all the security systems from a central location. Various security systems are :

- Web-based security surveillance system
- General Area Surveillance System Central Monitoring Station (CMS)
- Visitor Tracking and Employee Time Attendance System

Web-based Security Surveillance System

The sprawling campus of BARC has been divided into several zones for administrative and monitoring convenience. Each zone has a Local Control Centre (LCC) typically at the Assistant Security Officer's (ASO) desk. This system is intended to monitor the security posts in restricted areas and enables

Web based Security Surveillance

authenticated users to monitor the LCCs by viewing simultaneous streaming videos and distress alarms from the security LAN. Each LCC has a network camera, a PC, a hooter and a hidden switch conveniently located in the reach of the ASO. The LCC in distress can press this switch and alarm is annunciated in all other LCCs.

General Area Surveillance System

This system has a fixed number of camera assemblies and a core surveillance system at the LCCs. It is primarily meant for monitoring the movement of vehicles and casual labour. The monitoring is done both locally and from the CMS. Video recording facility has been incorporated. This system operates over security LAN.

Central Monitoring Station

This is located at a Central place and is manned 24x7 by security personnel. The web-based surveillance and general area surveillance system are monitored both on security LAN and reverse cable TV network here.

Visitor Tracking and Employee Time Attendance System

This system has been developed to track the visitors & employees at any point of time inside BARC Campus. This system is also used for the attendance purpose of the employees. Whenever an employee or a visitor flashes his RFID based card in front of the RFID reader, the information stored in his card is validated against the authorized data stored in the centralized database. This information is used to regulate the entry of the personnel to restricted areas and to keep track of the movement of the personnel. Along with the time stamping, this system is used to monitor and log the attendance of the employee. Daily employee attendance data available on the central server can be used for overtime

Snapshot of Visitor Tracking System

computation and leave records.

Web-based Monitoring and Control

In addition to the physical protection applications, the Web technology has been exploited to provide the virtual environment of a lab or a setup on a website and to allow monitoring and controls. This enables us to remotely view any experimental setup and monitor environmental parameters of the lab using either streaming video or snapshots refreshed periodically depending on the network bandwidth available. With this, one can remotely control the equipment also. In the concept of multi level authentication scheme has been employed. This has been implemented for monitoring ANUNET stations and distributed Computer Centers within BARC campus.

The same philosophy, with specially designed interface is being applied to the remote operation of Tactic Control room of the GOALS Observatory situated at Mt. Abu, from NRL Trombay premises, over ANUNET.

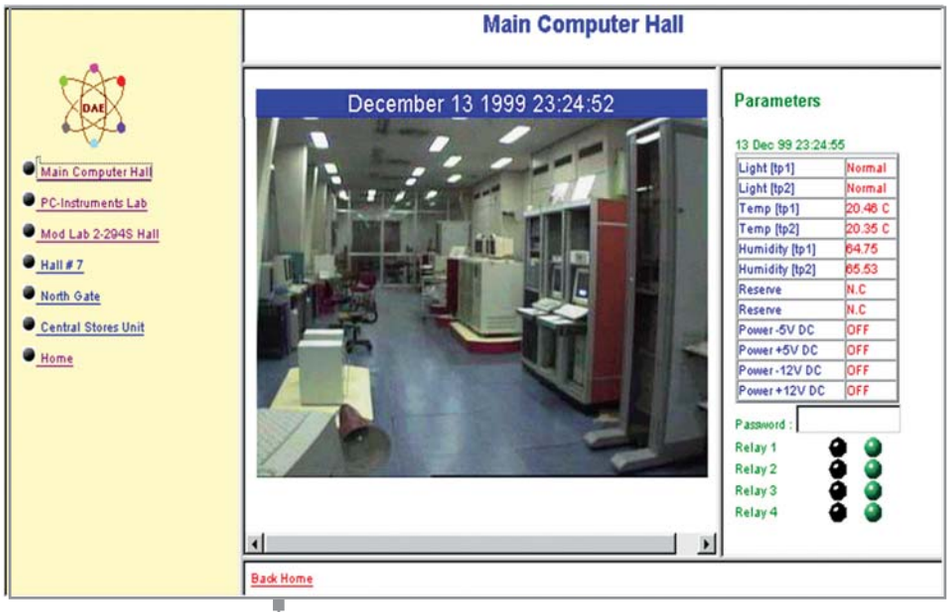
The web-based control & monitoring system with few modifications was deployed during VVIP's visit for remote inauguration and video viewing of the events of remote sites.

Web based environment monitor and control system - HK Kaura, VS Indurkar, PS Dhekne, JJ Kulkarni, L Prasad Babu and UC Lad, **BARC Newsletter, No. 192,** Jan 2000.

Web based remote instrumentation and control - PS Dhekne, JV Patil, JJ Kulkarni, Prasad Babu, UC Lad, AG Rahurkar and HK Kaura, **INIT 2001,** Mumbai.

Hand Scan Biometric System

A new image processing technique based on simultaneously matching the multiple and distinctive 2-D image patterns on fingers from nail side of the hand at predefined geometrical positions has been developed for biometric verification. Biometric techniques are based upon fundamental features that are derived from unique physiological or behavioral characteristics of a person. These characteristics include fingerprints, hand silhouette, iris pattern, blood vessel pattern on the retina, facial features, signature dynamics and voice pattern. BARC has researched the potential of using hand as a biometric identifier in a different way and importance was given for comfortable placement of hand i.e. with palm side resting on a baseplate and the CCD camera seeing the nail of hand from the top.



Web Based Monitoring System showing Computer Center Scan

A prototype Hand Scan Biometric System to demonstrate the technique has been developed. It consists of an Imaging Unit with pegs for guided placement of the hand and a PCI bus frame grabber, integrated around a Personal Computer. The hand image acquired by a video camera in the imaging unit is digitized to 768x576x8 bit resolution using the PCI bus frame grabber and is then transferred to the PC for further processing. Basically, it is a one-to-one system, in which a live sample provided by the user is compared to the pre-stored template according to pre-defined accuracy limits. This technique of verifying the identity of an individual involves following two major steps.

Registration : The system first captures from nail side of the hand image, multiple distinctive 2-D patterns on fingers. This is known as the registration process. These 2D patterns in the hand image of the individual along with their coordinate information are used to form a unique template, which can be used for his/her subsequent verification against a live sample. A Personal Identification Number (PIN) is allotted to each person at the time of registration.

Verification : During verification, the Individual using the system is required to type the PIN to call up his record. A live sample provided by him/her is compared to the pre-stored template according to pre-defined accuracy limits. Based on this comparison, multiple parameters are computed. These parameters indicate degree of similarity of template patterns with respect to the corresponding patterns in verification image and also the geometrical distance between some of these patterns. A Quality Degradation Factor (QDF) is computed based on the deviations observed in these parameters and user's claim for identity is accepted or rejected depending upon the threshold limit set for this factor in the template.

Verification in Progress

Three systems based on the above technique have been installed at three different locations for evaluation. These systems are continuously in use and are working satisfactorily. No case of False Acceptance has been reported so far on of these systems. One more system was installed at ECIL, Hyderabad during March 2005 for demonstration and to initiate the Technology Transfer.

Applications

This development will find applications in the areas of access control to high security zones, time and attendance, implementation of health and social services schemes etc.

■ Security System (Cyber Domain)

Information Security deals with a gamut of problems, which have come with the advent of fast growing Internet technologies and network-based communication. Now a days, the issues of defacing of websites, Information stealing from organizational network, acquiring control of information systems etc. have assumed gigantic proportions. These result in extensive loss of business, revenue, credibility, efforts and reputation. To address these issues, Information security management in any organization needs a professional approach. Keeping in view the stringent security needs of our organization, Computer division, BARC has evolved methodologies to implement secure practices and developed tools to manage and monitor them.

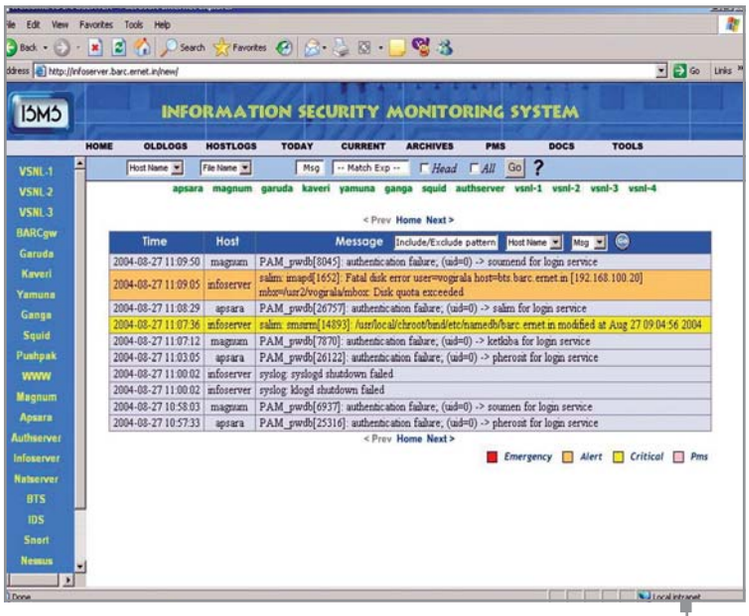
■ Management of Internet Services with Secure Practices

Computer Division is currently managing multitude of Internet services employing state-of-the-art security practices. The practices include design of network architecture with defense-in-depth policy, using secure & multiple operating systems and applications, Access Controls at various network levels, Firewalls,

Intrusion detections systems, Encrypted services, Security monitoring & Analysis, Virus & Spam control and Security Auditing. The multi-layered network architecture limits access of BARC services by external sites to required minimum. The use of multiple operating systems and applications prevent a given intrusion technique (common mode failure) from being successful across all network layers. Access controls minimize the misuse of services, and aid in activity monitoring. Firewalls and Intrusion detection systems prevent, detect & stop unauthorized activity. Encrypted services maintain the confidentiality of passwords and data. Virus & Spam controls stop damage to user systems due to malicious content in email and web data. Security Auditing is an activity regularly carried out to investigate whether the security state of the systems and services conform to policy framework and undertake necessary actions.

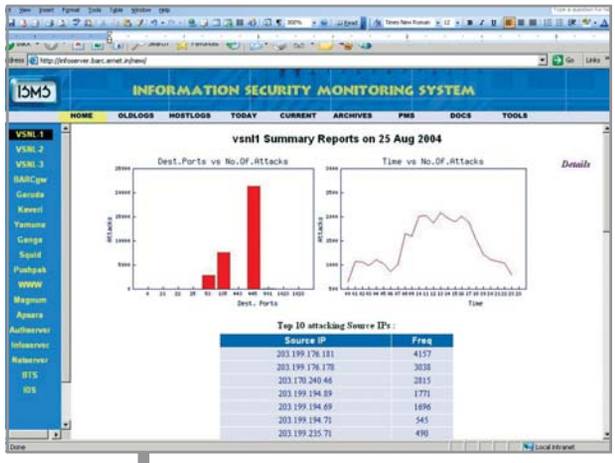
Information Security Monitoring System

Monitoring of systems and applications rendering secure Internet services is essential to detect and take preemptive action on unauthorized activity. In BARC there are large number of systems involved in Internet activities. It is practically impossible to monitor and analyze the information provided by all the systems in such a distributed environment on individual basis.



Log Monitoring on Information Security Monitoring System

Computer Division has developed a centralized monitoring system to achieve the objective of monitoring and analysis of Internet systems. The system has the components Online Log Monitoring and Alert, Firewall Analysis, Host Security Reporting, Internet Applications Analysis, Logs Archive & Searching, Internet Links Status Reporting built into a central monitoring web server. It is based on client/server architecture, clients being the Internet servers.



Firewall Analysis on Information Security Monitoring System

Spam Management Software for Windows Desktops

Unsolicited commercial emails (advertisement for products etc) also known as 'Email spam' is a wide spread problem on the Internet. It results in wastage of Internet bandwidth, server & disk resources and also brings lot of inconvenience and embarrassment to email recipients. Computer division has adopted measures like spammers database, spam-filtering software, Domain Name Service based rejections etc to control spam. One more effective way to control spam is to make use of spam information provided by users. BARC has a large email user base and information from them could be effectively used to control spam. Spam Management software has been developed for this purpose. The software has made the build up of spammers database and self-learning process of spam filter software faster, resulting in highly efficient spam management tool.

5.3 INFORMATION MANAGEMENT SYSTEMS

In a multi-disciplinary research and development organization like BARC, where more than 4000 scientists and engineers are working in frontier areas of science and technology, it is humanly impossible to keep track of various achievements, expertise and publications of any individual if one is interested in knowing such information. In such an environment, there is an immediate need to organize data and provide fast searching and retrieving mechanisms with easy-to-use graphical user interface. The proposed facility contains the collection of data pertaining to employee's information and general information. The employee's information contains data like his/her expertise, developed products, areas of interest, activities etc. General information may contain circulars, announcements, calendars, internal telephone/email directory and homepages of divisions and scientists/engineers.

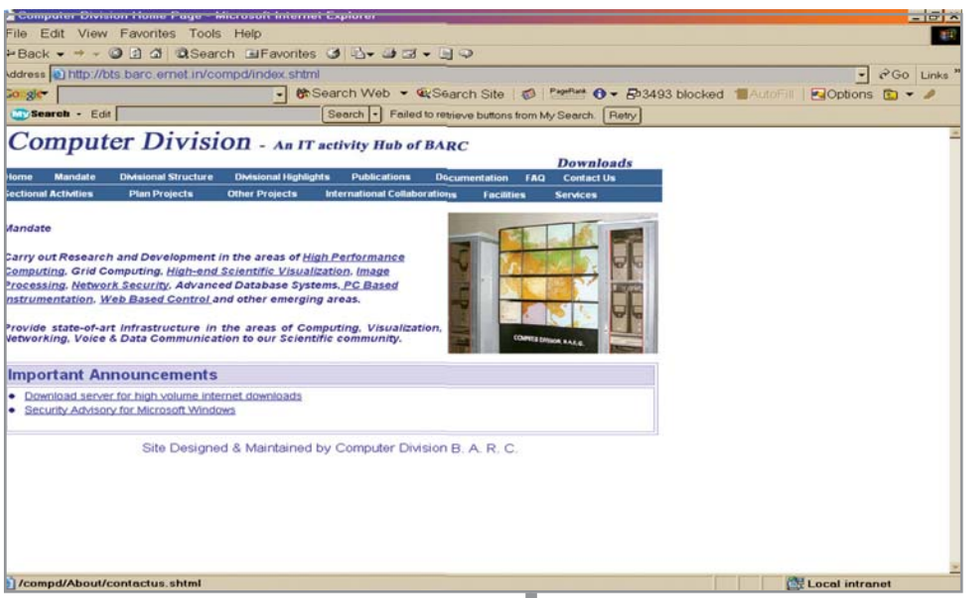
■ BARC Technology Synergizer (BTS)

BTS is an attempt to present the users of BARC with this facility where users can browse in the database and can interactively retrieve all the needed information. BTS is implemented on top of a web server to facilitate users of BARC to communicate and to access the information. BTS fulfills the above specified objectives and also provides platform to encourage scientists and engineers to freely exchange their ideas and solutions to the problems with their colleagues located somewhere on the organizational network. In this way BTS provides them a platform to synergize multidisciplinary activities, which otherwise becomes very difficult to launch.

BTS provides area to each employee of BARC to login and update his/her information about expertise, developed tools/ products, publications (national/International), present activities, membership of various committees, involvement in various projects etc. This information can be used by general user for example to locate employees with required skill-set. With this information BTS becomes useful for management also for various tasks like formation of task-force/ committees, reviewing employee's career-profile, monitoring plan projects, monitoring usages of expensive/ specialized facilities etc. BTS is currently being used extensively in BARC by employees in general and decision making bodies in particular.

■ Hospital Information Management System

BARC runs a speciality hospital and many dispensaries serving healthcare to its employees and family members. In order to improve its operational efficiency, productivity and better patient service, a Hospital Information Management System (HIMS) has been developed. HIMS was developed on a server client platform under Oracle and D2K. Major hospital activities such as patient registration, appointments, scheduling, token allotment, referrals to other hospitals, patient clinical details, operation scheduling, referral bills, admission discharge status and statistics, duty roster and various reports have been computerized and are fully implemented in some OPDs. The referral forms and appointment modules for other OPDs are customized and implemented. All types of pathological reports have been



Computer Division Website on BTS

fully computerized. The manual system for appointments has been completely dispensed with.

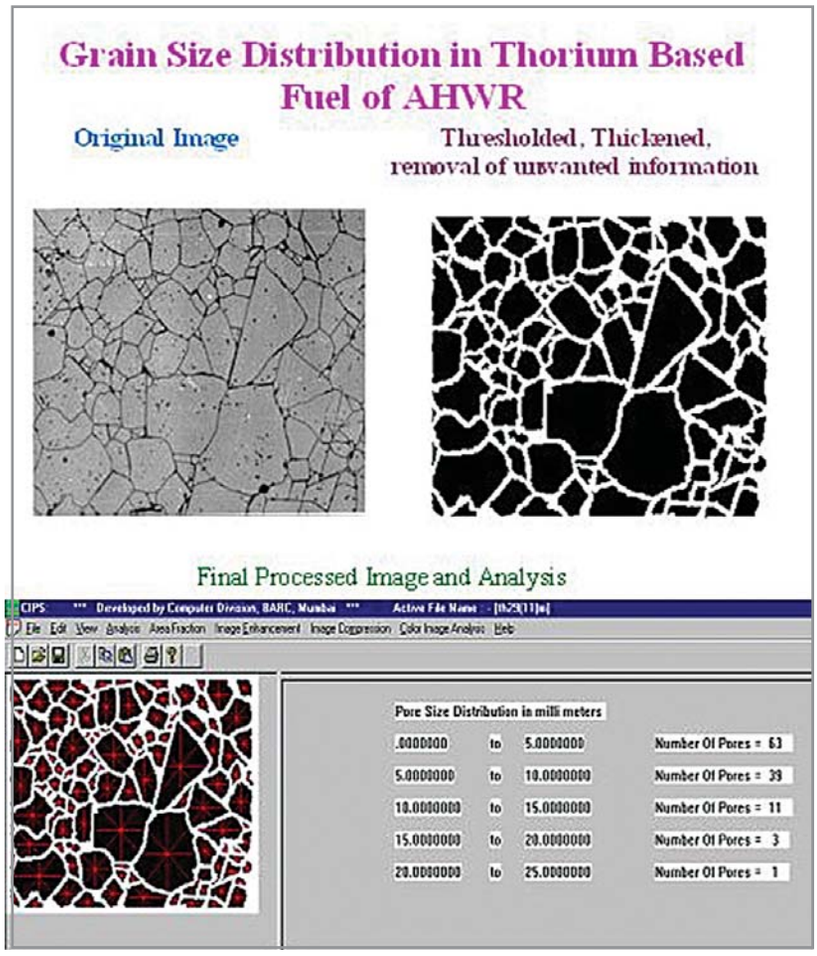
■ Information Management System for DHRUVA/ CIRUS

Work on Computerized information system for Atomic Fuels for the data management of DHRUVA/CIRUS fuel fabrication is in advanced stage. The data typically consists of raw material data, process control data, product data, quality control data and inspection data. The system has security features, including authentication by different groups at every stage of the manufacturing cycle, developed using a task-security mechanism so that only relevant production data is visible to different production groups.

5.4 APPLICATION SOFTWARE DEVELOPMENT

■ Image Processing Application Software Development

Computer Division has developed a number of Software Packages for addressing specific Image Analysis problems in various fields of Nuclear Science and Engineering. These packages consist of various software modules supporting image enhancement and processing operations on different platforms such as Personal Computers, Workstations under Windows 98 / NT environment, Unix / Linux based systems and ANUPAM Super Computer system. The image processing routines are developed in C, C++, Fortran and JAVA languages. These packages have addressed many interesting real life problems such as Detection of grain defects and spoilage, Morphometric analysis of wheat grains, Quantitative analysis of Aphids attacking a leaf etc. in the field of Agriculture and Life Sciences. Further, in the field of Nuclear Engineering, these packages have been used for studying Grain size distribution in Thorium based fuel of AHWR, fuel pellet microstructures, Hydride platelet content, Morphology of Zircalloy-2 pressure tubes etc. In addition, these packages have found use in numerous applications in the fields of Chemical and Physical Sciences. Two typical applications are illustrated next.



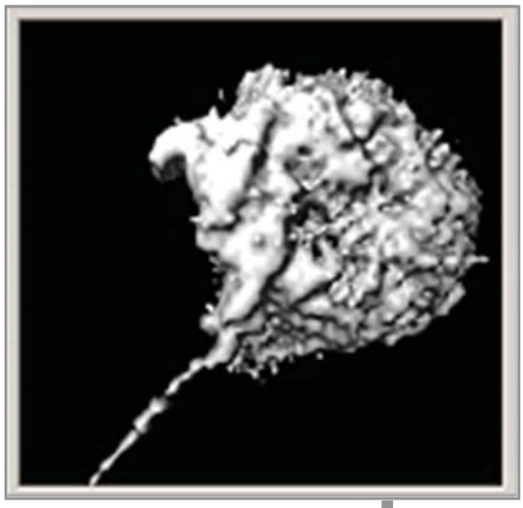
Grain Size Distribution In Thorium Based Fuel Of Advanced Heavy Water Reactor (AHWR)

Grain Size Distribution is necessary for evaluating the proportion of fuel and fission gas released. Images of the grains are captured and joined regions (grains) are separated prior to Image Analysis. Computation of average size of various grains is performed by computing average of automatically drawn diameters at different angles in a region.

Image Enhancement Software

An Image enhancement package based on the open source software VOLVIS has been developed with the following features:

- Identification of Connected 3D Objects in a Scene.
- Computation of Statistical Moments, Kurtosis Measure for 3D Object.
- Measures of Volume, Surface Area, Peak Count and Voxel Intensity for each Identified 3D Object.
- Distance Measure on Surface of 3D Object.
- User Interactive and Automatic Measurement Modes supported.
- Rigorous Online Help with Index Search has been provided at each stage of operation.
- File Conversion Utility for converting .PIC files to .SLC files.



Rendered 3D Image of a Cell

Currently, this package is being extensively used by Adavanced Center for Treatment, Research and Education in Cancer (ACTREC), Kharghar, Mumbai.

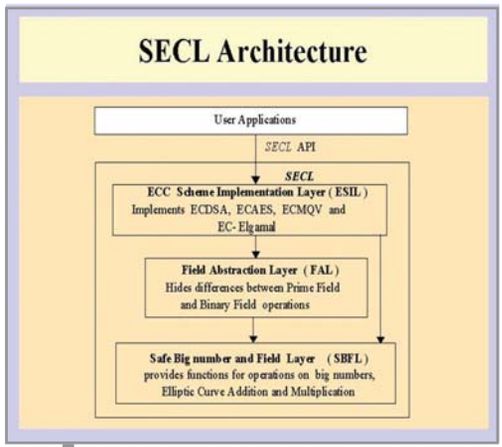
Artificial Neural Network (ANN) Applications

An Artificial Neural Network (ANN) software using resilient back propagation algorithm was developed and applied in prediction of channel power distribution of 220 and 500 MW PHWRs and calculation of thermal hydraulic parameters. Development of a full-fledged ANN package BIKAS (BARC-IIT Kanpur ANN Simulator) at IIT Kanpur under a BRNS project was completed. BIKAS consists of 20 algorithms, 18 error functions, 26 activation functions, Fuzzy logic algorithms and several combinations of ANN and Fuzzy logic algorithms. To disseminate the knowledge of ANN and BIKAS in BARC scientific community, a BIKAS User's Group (BUG) consisting of members from various divisions of BARC has been formed. The members of BUG are using BIKAS for solving problems in their respective areas of interest. A BRNS-sponsored Theme Meeting on ANN was also organized in BARC. Software Requirement Specification for re-engineering BIKAS in C++ is under development.

A software package called Vibration Signal Analyzer using Fourier Transformation and ANN (ViSFoTA) was developed. This software is useful in the analysis of vibration signals in general and seismic signals in particular. It can be trained to distinguish an underground nuclear explosion from an earthquake. The software was developed in Reactor Control Division in collaboration with Seismology Division of BARC.

Elliptic Curve Cryptography (ECC) Crypto Layer Software on Linux

Software called Safe ECC Crypto Layer (SECL) based on Elliptic Curve Cryptography (ECC) has been implemented on Linux platform. SECL operates in safe memory mode on Linux i.e. all plain text and keys are handled in memory pages, which are not swapped, to disc, thus leaving no trace of plain text and sensitive keys after a SECL function execution.



Architecture of Crypto Layer Software

A user API provides access to SECL functions. The SECL implements IEEE-P 1363 schemes EC-Elgamal (encryption-decryption), ECMQV (key negotiation scheme resistant to man-in-the-middle attack) and ECDSA (digital signature generation and verification). SECL supports key sizes ranging from 160 bits (equivalent to 1024 bits of RSA) to 512 bits (equivalent to ~ 15K bits of RSA) using Prime and Binary fields.

The SECL also runs on Simputer - Linux-based PDA running 20 MHz ARM processor, making it possible to develop secure applications on PDA. The hardware implementation of SECL in FPGA is currently underway using Handle-C language. Handle-C can be directly compiled for loading into FPGA.

Software Implementation of a Crypto layer using Elliptic Curve Cryptography, Sharvan Kumar, B.R. Ivan and S.D. Dhodapkar, **National Workshop on Cryptology,** Amrita Vishwa Vidya Peetham, Kollam, India, 2004

5.5 COMMUNICATION INFRASTRUCTURE

The integrated data voice network of BARC, with 7000 terminals and having advanced network management system, has been augmented to support standard ISDN access to computer networks at 128 Kbps from 2000 points. This is one of largest ISDN LAN in the world. ANUNET, a DAE-wide multimedia satellite based network, bandwidth has been doubled and applications requiring on line and real time data acquisition have been ported onto ANUNET. Online data communication facility has been implemented at 15 sites.

■ BARC Campus Wide Network

A Campus wide TCP/IP Network Infrastructure has been created using active high-speed networking components with Gigabit Ethernet backbone and a mix of Monomode and Multimode Optical Fiber Cables and UTP copper cables. The Campus Network is a very large one, both in terms of number of Computers and the geographical distance covered. This network is a collection of various physically or logically separated networks like Computational Network (Compu-Net), Information Network (BARC Intranet), Secured Internet Network (also includes Dial-up users), DAE-wide Network (ANUNET) etc. These networks offer various services to a large number of users base amounting to above 3000. We are aiming towards providing *secure unified access* to various network services. Many services such as Computational Services, BARC Technology Synergizer (BTS), E-mail, Library, Stores & Purchase information, Internet, ANUNET access, Video Conferencing, On-line Complaint Registration, Web Casting, etc, are provided on BARC networks.

■ S-NAS: Secure Network Access System

Information systems have become one of the most critical and invaluable assets of an organization. Loss of data and information could sometimes mean bringing the entire operation to standstill. Today, threats to information system arise primarily from use of multi-user computer system connected over networks. The S-NAS (Secure Network Access System) provides a centralized way of monitoring and managing the network components and computer systems connected to the computer network. It provides client computer systems with secure access to the network and its services. It is based on the client-server three-tier architectural model. The S-NAS client program has to be loaded on all computer systems in the network. The S-NAS client sends network related information to the S-NAS server at regular intervals. The S-NAS server **controls** the computer **network devices** (Ethernet Switches) for providing access to computer systems into the network based on the data received from S-NAS client.

■ DAE Wide Area Network: ANUNET

ANUNET is a fully meshed wide area multimedia satellite network used by various DAE units for their communication needs. It interlinks 39 sites covering all the Units and Aided Institutes of DAE. The backbone of the network is a VSAT (Very Small Aperture Terminal) based satellite network using highly flexible Multi-carrier TDMA access scheme and Frame Relay technology. This network is used for secure voice, data and video transmission to any other unit over satellite. ANUNET uses quarter transponders of INSAT 3C & INSAT 3A satellite. The total available bandwidth is 18 MHz (13.4 Mbps). Major DAE sites are either directly connected to ANUNET or indirectly connected via a common site having ANUNET connectivity.

Both secure and Normal Data channel Networks use network level encryption (IPSEC) with digital certificates. The Voice Network supports over 80 simultaneous conversations. The voice traffic between BARC and ANUNET, on a typical working day, is about 2000 calls. Anunet provides services like Voice Communication, Web Casting, Remote Site Monitoring, Online Data Acquisition etc.

IT Services

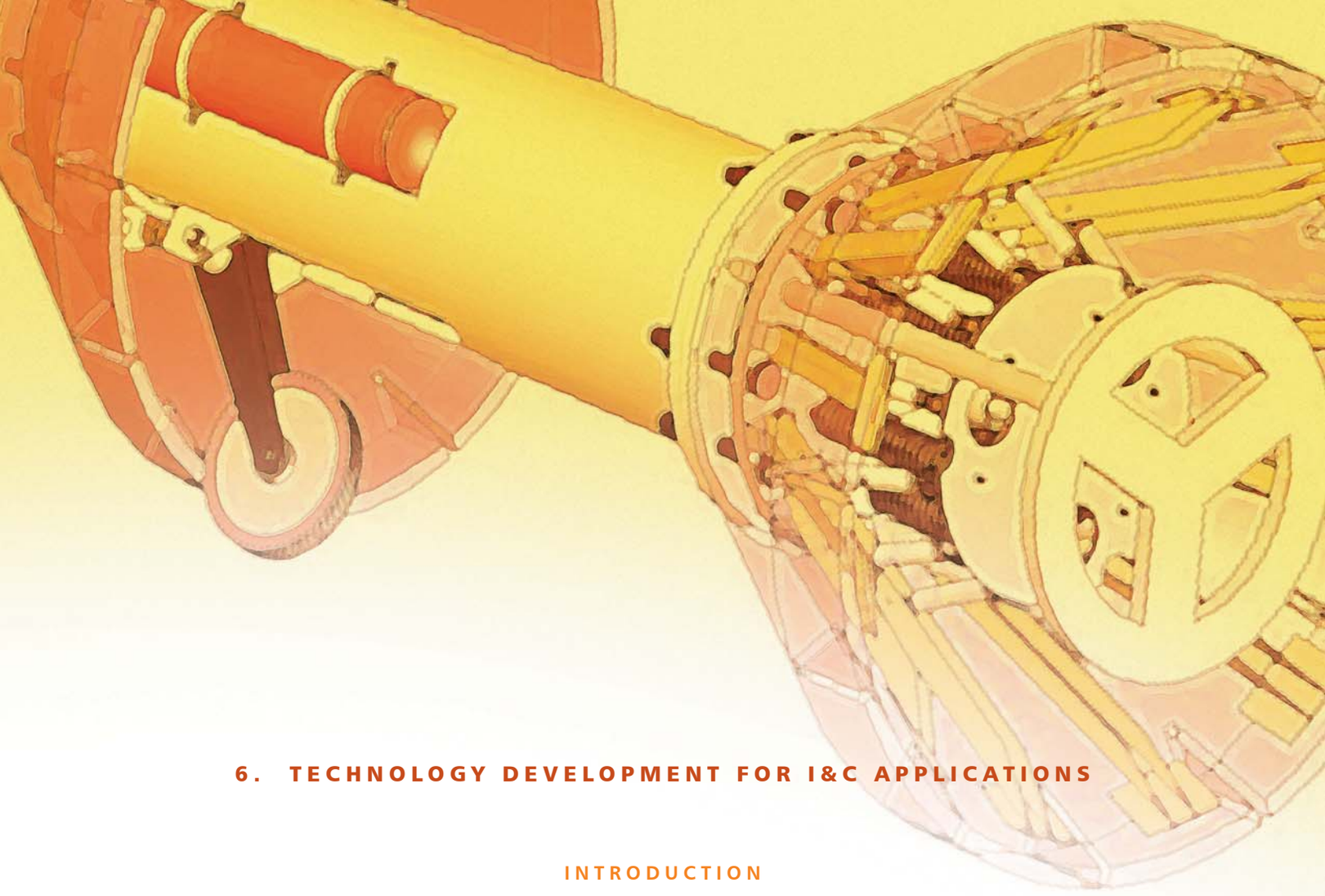
Computer Division, BARC, provides the state-of-the-art computing services to BARC personnel. In addition to the indigenously developed parallel super computer, Computer Division has advanced hardware, software, scientific libraries, latest Fortran, C, C++ compilers and other supporting facilities needed by the large scientific community. In all, we have about 10 computer centers at different locations in BARC. All of them have been interconnected together to form a physically isolated Compunet, so that resources available of all the computer centers alone can be shared in a secured and transparent manner. Users have been provided access to Compunet either from the PCs located inside the computer centers or PCs from respective user rooms through ISDN.

Computer Division has setup secure Internet and Email infrastructure effectively covering the large campus of BARC incorporating multilayered security infrastructure. To facilitate their usage, we have setup about 30 common surfing centers covering all major locations. This covers virtually every employee of BARC who heavily depend on these facilities for their communication needs. Apart from this seniors have been provided Internet access through ISDN connectivity.

Computer Division also operates LAN based INFONET, an information network, spread across all BARC campus and covering main areas inside every building. The Infonet provides access to various information servers such as BTS, Online Library, Accounts, Admin, DPS etc.

Computer Division, BARC has established an INTEGRATED DATA-VOICE NETWORK, which is based on ISDN (Integrated Services Digital Network) technology. This network comprises of seven ISDN Telephone Exchanges providing voice communication within BARC and connectivity to MTNL voice network. It also provides connectivity to other telephone networks of various DAE units via ANUNET. The total capacity is about 6500 lines. The ISDN network consists of about 1500 ISDN lines, which provides ISDN Standard 2B+D interface in addition to a concurrent telephone channel on each line. The network provides users with advanced services such as Call-by-name with centralized phone book, Voice-mail Service, Conversation recording, Teleconferencing facilities and a host of other utility services. In addition, it also provides ISDN dial-up access at the speed of up to 128 Kbps to Internet and other computer networks through a bank of Remote Access Servers (RAS). In conjunction with our wide area network (ANUNET), we provide Video Conferencing facility, Voice and secure data communication across different units of the Department of Atomic Energy.

Computer Division also has setup CCTV network across entire BARC campus for display of all major events, seminars, notices etc. This network is also being used for covering online video coverage of seminars in Central Complex Auditorium.



6. TECHNOLOGY DEVELOPMENT FOR I&C APPLICATIONS

INTRODUCTION

BARC has always been on the forefront of technology development in the area of nuclear application as well in other areas important and strategic for the nation.

A Mobile Robot has been developed for surveying of hazardous areas and another for demilitarization of anti-tank fuze has recently been developed. Remote robots have also been developed for Indian Navy for performing the hazardous job of fuelling rockets and missiles.

For inspection of oil pipelines of Indian Oil Corporation an Instrumented Pipe Inspection Gauge (IPIG) has been developed to assess corrosion state and other defects at any section of pipeline extending over hundreds of kilometers.

Application Specific Integrated Circuits (ASICs) have been developed for detection and analysis of radiation for various applications developed by the centre.

Acoustic Emission Technique (AET) has been developed for inspection of reactor structures and components for detection of cracks and leakages.

Technologies have been developed for medical applications; notable among them being Impedance Cardio-vascograph and non-invasive blood pressure monitor for ICCUs.

New development of instrumentation modules have been made for advanced application of Ultrasonic techniques for Non Destructive Testing (NDT) of critical mechanical components for reactors.

For Indian Railways, a safety device called Eddy Current based Wheel Detector has been developed.

Techniques for Vibration based monitoring and protection system for heavy plant machineries has been developed. Also image processing techniques have been developed for fracture mechanism studies of mechanical components.

6.1 ROBOTICS & AUTOMATION

The primary aim of R&D activities in Robotics and Automation in BARC has been to develop technologies and solutions to reduce radioactive exposure to the workers and operators in our nuclear reactors and other radioactive installations and laboratories. Some of these technologies are also relevant for handling hazardous chemicals and explosives remotely. In what follows, we list the developments of technologies and applications mainly in the areas of mobile robotics and automation. We also list novel adaptations of our mechanical master slave manipulators in the fuelling of rockets and missiles in the Indian Navy.

■ Mobile Robot for Remote Survey and Inspection

A mobile robot nicknamed SmartNav (Smart Navigator) has been developed for the purpose of remote survey and inspection of hazardous locations. The robot measures about 50 cm long 50 cm wide and 30 cm high and is powered by onboard battery. It has two drive wheels and one castor for support.

A microcontroller controls the motion of the vehicle under commands from a high-level program running on an onboard computer. This program in turn communicates with a stationary host computer through wireless Ethernet. An operator operates and monitors the robot through the host computer.

SmartNav: Mobile Robot for Remote Survey & Inspection

One SICK Laser Range Finder is mounted on the robot for obtaining accurate range data of its environment. A pan-tilt-zoom camera enables the operator to view and inspect the environment of the robot remotely. Computer programs have been developed to incrementally build a map of the robot's environment and to correct its knowledge about its own position and orientation using the laser range data. A graphical interface has also been developed for the operator to issue commands to the robot, view its environment and monitor its location on the map remotely from the stationary host computer.

■ Mobile Robot for Ordnance Disposal

A Mobile Robot was developed with a manipulator for removing and defusing fuze mines in boxes stacked in a room at Ordnance Factory Khamaria, Jabalpur.

SmartROD: Robot for Ordnance Disposal

The vehicle is driven remotely through a RF link from a control desk primarily by watching on TV monitors the video images received from the PTZ camera units mounted on the vehicle and the manipulator. The vehicle has a Laser Range Finder mounted at the front to warn of potential collisions. Once the vehicle is positioned approximately at the desired location with the right orientation, the wheels lock in position.

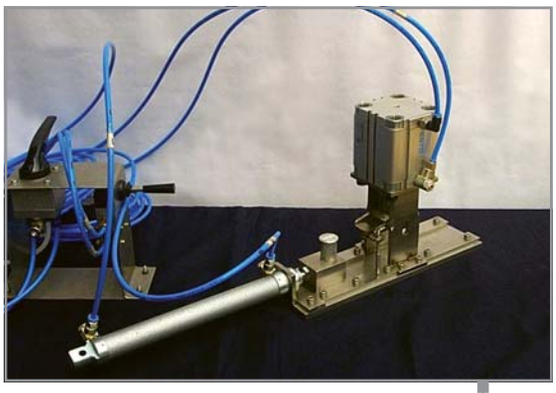
The manipulator can now be used remotely to pick up a box and place it on the vehicle. The vehicle then carries the box out of the room to a safe location for disposal.

■ Automated Gamma Scanning System for Isotope Application Division, BARC

Isotope Application Division is using Co_{60} and Cs_{137} radioisotopes for inspection of trouble shooting and process optimisation of industrial process columns. DRHR has designed and fabricated a prototype drive unit for automated scanning of process columns. The mechanical assembly consists of two SS grooved drums, pulleys, steel wire rope assembly, rope slackness detection, base frame, geared motor unit and PC based controller. A special explosion proof AC servomotor is used to drive the unit, which has built-in high

Prototype Drive Unit Assembly for
Automated Gamma Scanning

resolution encoder. The motion is fed through an automated PC based controller giving flexibility in operation. The drive unit gives very high positional accuracy. The source/detector position in real time is displayed on monitor (graphical as well as numerical value) along with detector output. Also the data is acquired and stored in hard disk and hard copy of detector output can be obtained using printer.



Remotely Operated Automated
Irradiated Aluminum Can

In-cell Automation

DRHR has developed an In-cell Automation system to feed rubber bung, Aluminum cap and then seal the glass vial after dispensing the radiopharmaceutical products of high activity. The system operates on compressed air. The mechanical system is designed in compact modules so that it can be taken through the transfer port opening and installed inside the cell.

10-ml Vial Crimping Unit Installed
in ^{131}I- Processing Plant

The Rubber bungs and Aluminum caps are preloaded in cartridges transported into the cell and then inserted at respective column using a tong. Two sizes 10 & 15 mm vials can be accommodated in the system. Using a tong, a fresh vial is kept inside a vial holder and the radiopharmaceutical product is dispensed. The controller is kept outside the cell. On pressing a button, the vial moves under the rubber plugging station where the rubber bung is plugged and then it is carried to the vial sealing station. On the way it picks up an aluminum cap that hangs from a chute. After sealing by the tool, the vial is pushed out for removal. Safety is provided in the design so that no spillage or vial package occurs during the entire operation. The system is installed at BRIT, Vashi.

Remote Missile Fuelling System for Indian Navy

Certain missiles of Indian Navy use liquid propellants as fuels. The fueling and defueling operations are dangerous as these fuels are highly inflammable, toxic and corrosive. DRHR has developed a Master Slave manipulator based remote handling system to perform these operations. The system is supplied and installed at INS, Tunir, Uran.

Master Slave Manipulator in Missile Fuelling

Arming the Booster of Surface-to-Air missile for INS Tunir, Indian Navy

The fuel of RZ-61 Rocket consists of 14 sticks of about 1.2 meter long each weighing about 20 kg. The sticks are toxic in nature. The loading of sticks into booster casing takes about half an hour for 4 to 5 operators. DRHR has developed a system that can do the same job in the same time by one operator. The system has been fabricated and is under testing. This ergonomically designed system reduces exposure of operators to toxic vapors.

Setup for Arming the Booster

P.K.Pal <drhr07@barc.gov.in>

6.2 INSTRUMENTED PIPE INSPECTION GAUGE (PIG)

Crude oil and other hazardous oil products are often transported in the pipelines, through thickly populated areas. Mandatory monitoring of the condition of these pipelines is necessary to ensure public health and safety and to avoid loss of costly product. In-line inspection of these pipeline are carried out periodically by hiring services from foreign vendors at a very high cost. IOCL had approached BARC for the development of a pipe inspection gauge, also known as pig, for their pipelines. The development was undertaken under a Memorandum of Understanding between BARC & IOCL.

Launching at Mughalsarai Pump Station

BARC has successfully developed an instrumented pipeline inspection gauge (IPIG). The instrument has taken commercial trials in BKPL of IOCL. The IPIG works on the principle of saturating the carbon steel oil pipe section with high magnetic flux and monitoring the leakage flux on the inner surface of the pipeline. Two arrays of Hall sensors, primary and secondary, are used for sensing leakage flux. A wet evaluation facility was set up at R&D Center, IOCL, Faridabad, to assess the performance of instrumented PIG in actual field conditions.

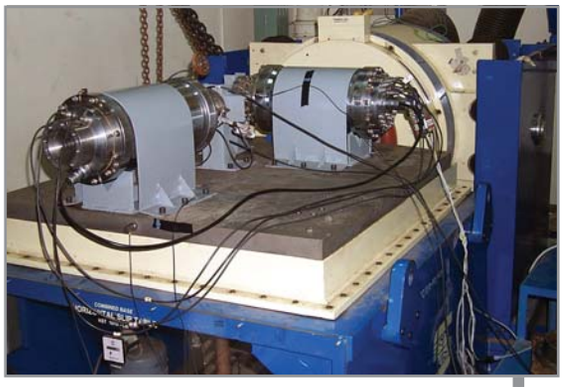
IPIG has been extensively evaluated in wet test loop, Faridabad. First commercially successful trial of IPIG has been carried out, in 162 km long Mughalsarai-Allahabad section of BKPL, IOCL in June 2003. The instrument mechanically negotiated all the critical pipe features and flux leakage data acquired was analyzed for localization and sizing of metal loss defects. The IPIG is now commercially available to inspect 12-inch aging pipelines. The commercial version of instrumented pig consists of magnetic module, data acquisition system module (DAS), battery module and pig locator module. The polyurethane cup mounted on IPIG, seals the pipe and the pressure of the oil flowing through these pipelines gives required propelling force for its movement. Front cups are sealing cups and other cups are supporting cups.

It also consists of 3 odometers to record distance traveled by pig. It is a very common phenomenon in pigging operation that odometer slips especially in presence of petroleum oil. The slippage is compensated offline with the help of magnetic markers installed on the outside surface of the pipeline at specified locations. The battery module also houses a supervisory circuit and a status logging computer system, to monitor the condition of battery and DAS electronics.

Micro-controller based inclinometer circuit was designed, developed and tested for measurement of inclination of IPIG during its travel in the pipeline. This information is useful in locating clock position of the faults. IPIG undergoes lot of

Inclinometer Electronics

vibration and shock during its travel through the pipeline due to interaction of its cups with pipe-features. The DAS and battery modules were qualified for rigorous vibration and shock in operating condition in three mutually perpendicular directions as per IEC 571. Special vibration isolator and positive arrest of connectors were designed for the flash disk. These tests were done on a shaker available at BARC, on a rotary test rig and in a 45° down-comer. All the cards, necessary electronics and flash disk are housed in a specially designed vibration and shockproof cartridge.



Vibration Testing of DAS and Battery Module

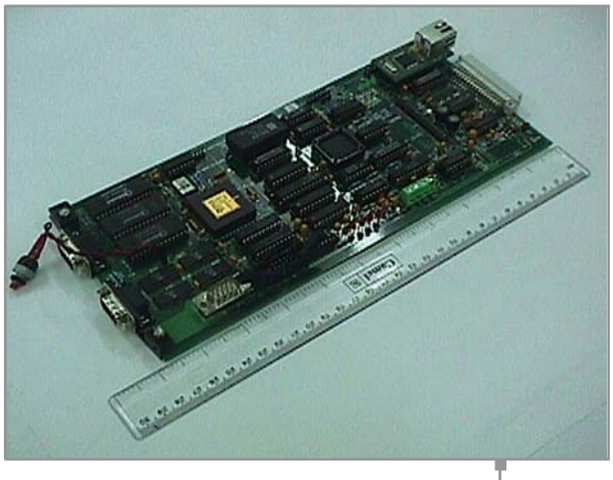
The present version of IPIG has miniature accelerometers mounted on electronics and battery cartridges to acquire the in-line vibration & shock.

A new prototype IPIG tool has been developed with hexagonal magnetic module and DSP based data acquisition system. Metallic sensors are used on ring to cover the pipe circumference uniformly. The new data acquisition system is an ADSP2101 DSP Processor based system. Size of uncompressed data at 12-bit resolution, collected per 100 km run of IPIG is of the order of 7 GB.

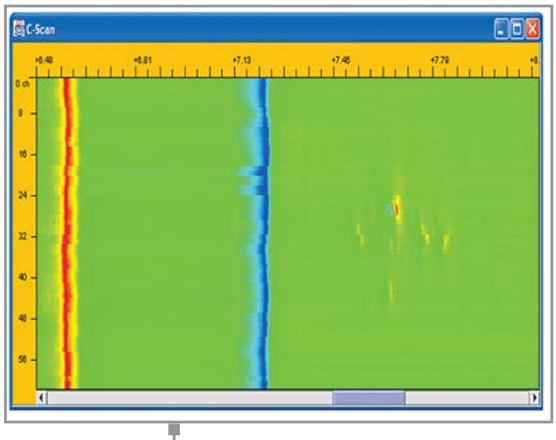
Handling and storage of large volume of data is cumbersome and costly. A large volume of MFL signal does not contain any information. We need to save only those parts of the signal, which contains information about pipe feature or metal loss defects. This requires taking a decision on-line if a particular part of signal contains or does not contain any information of interest. The solution is to threshold decomposed signal using wavelet filter. The technique has been implemented on the DSP hardware and the latest version of the data acquisition system uses the compression code.

DAS Cartridge

The data is analyzed off-line by defect inspection and interpretation software. The raw data is filtered in scale-space plane to eliminate noise due to sensor bounce, unequal lift-off, non-uniform pipe thickness, etc. The "de-noised" signal is used to form a surface-image of the pipe. Defect and pipe feature contours are detected and marked on the image and significant defect parameters are computed. An unsupervised defect characterization algorithm works on the segmented image and automatically generates a report giving details of the size and shape of the defect. Accurate defect



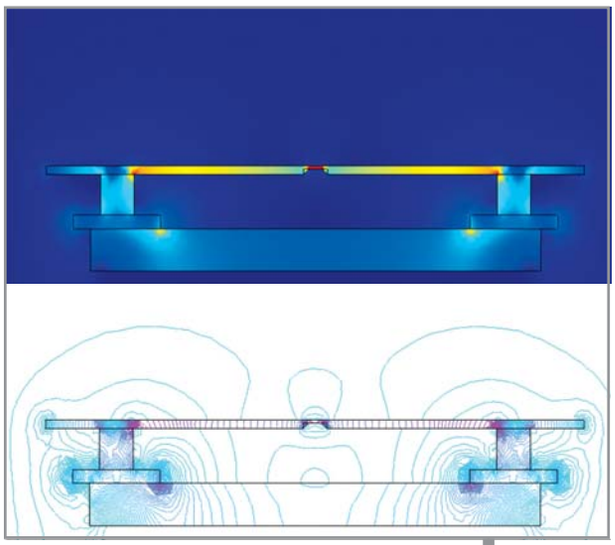
DSP based Data Acquisition Electronics



Data Presentation Package

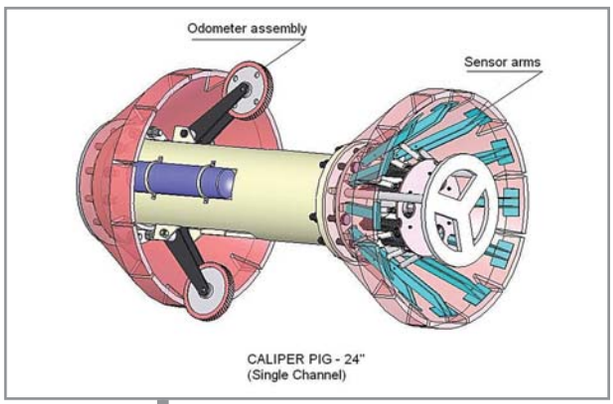
sizing requires matching the new defect signature with a member in the database. Alternatively, empirical formulae are used for estimating defect size and shape parameters from the signal. This report is eventually used for maintenance of the pipeline.

Closed form solution for the computation of leakage flux, around a defect, is not possible to find, in this case, due to non-linearity of the B-H characteristics of the pipe material. The leakage flux distribution around pits and notches can be calculated quite satisfactorily by FEM technique using commercially available packages. The leakage flux pattern is heavily dependent on the B-H characteristics of pipe material. Using the actual B-H characteristics of these pipe materials, 3D FEM models have been generated and the flux density distribution around the notch has been theoretically established and verified experimentally.



FEM Analysis of the Magnetic Circuit

Encouraged by the success of the present development IOC has shown interest in the development of other sizes of instrumented and caliper pigs. The design and basic developments are in progress. To meet the tight schedule of delivery, department has already taken up the activities like development of electronics using floating point DSP processors that can be used in both caliper as well as instrumented pigs, development of new type of sensors and sensor mounts etc. Long axial corrosion defects in carbon steel pipelines need to be inspected by subjecting the pipelines to circumferential magnetic fields instead of axial fields tools that are presently developed and are being used. The development of one such tool using transverse fields for the inspection of 12" carbon steel pipeline is in progress. This will help in detecting the axial cracks or faults of reasonable size which are more fatal as compared to circumferential faults of same size from the integrity of the pipeline is concerned. The design, analysis and fabrication of the prototype tool is nearing completion. Continuous efforts are made in improving the data characterization techniques with the help of FEM modeling and experimentation. A very effective data compression technique has been developed and being tested on actual data. In essence, a number of developmental activities are on to perfect the tool and technology and to achieve a high industry standard.



CALIPER PIG-24" (Single Channel)

Shiben Bhattacharya <amshiben@barc.gov.in>

6.3 ASICS AND HYBRIDS FOR NUCLEAR INSTRUMENTATION

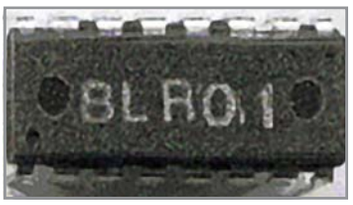
Due to rapid innovations in semiconductor processing technology, obsolescence of older devices becomes inevitable. This is serious consideration for the designers of electronic instruments and system, as their designs need periodic changes and updating. Instruments installed at reactor plants cannot be changed rapidly as qualifications at different stages are involved. The usage of commercially available devices is subject to hindrances due to export regulations / restrictions imposed by other countries. Fortunately, the remedy against

such constraints is offered by innovations in semiconductor technology itself. Standard digital devices like logic gates, flip-flops etc. were routinely used in digital designs since last 30-35 years. However, today much more complex and Programmable Logic Devices (PLD) as well as Field Programmable Gate Array (FPGA) are readily available. These devices are field programmable and allow the user to combine a complex digital logic design into a few PLDs or a single FPGA. Other advantages of such integration are: i) smaller physical size (one PLD chip may easily do the job of 10-15 standard digital ICs) ii) less power dissipation, iii) better reliability (due to reduced external connections) and iv) rendering a 'proprietary' touch to the instrument. The next step in this direction is to translate the entire electronic circuit into a customized single chip i.e. the ASIC. With the help of foundries available in the country (SCL, Chandigarh, SITAR, Bangalore), it is now possible to design ASICs in-house and have the devices fabricated at these labs. ASICs, which are employed to realize a single chip solution to an electronic design, need to integrate analog and digital circuits. This is a complex and expensive solution but it offers a proprietary device and the designer is no more dependent on other commercial vendors/ manufacturers. In nuclear reactor and other instrumentation systems, development of ASICs has now become essential. Anticipating such needs, a program for development of ASICs has been initiated since IX plan. During last 3-4 years a number of ASICs have been developed and some have been incorporated into prototype instruments also. Few Intellectual Property (IP) Cores such as 8051 microcontroller and GPIB have been developed in collaboration with other organizations such as IIT (Mumbai). These cores are then burnt in FPGAs along with other application related logic for higher level of integration. Some of the ASICs and Hybrids successfully developed in last 2-3 years are described below.

■ ASICs

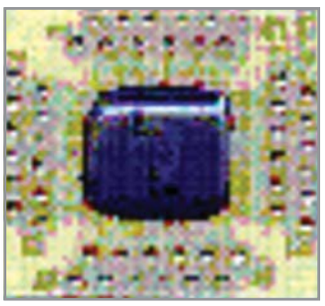
BLR (Baseline Restorer)

The BLR ASIC was made with the linear array developed by BEL. This array contains a collection of assorted resistors, bipolar transistors of PNP and NPN types and capacitors on a single die. The required analog functionality can be obtained by interconnecting these assorted components. The BLR ASIC is used as an auxiliary functional block in nuclear pulse shaping amplifiers.



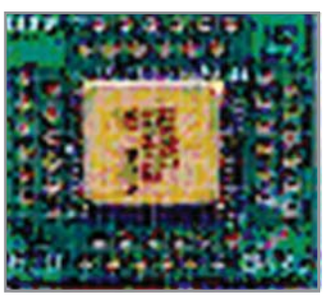
ADAM (ASIC for Dose Accumulation and Measurement)

The basic functionality of ADAM is to count pulses and display the same. It provides other facilities like dose alarm setting and computer readout is provided to implement computerized personal dose management for health safety.



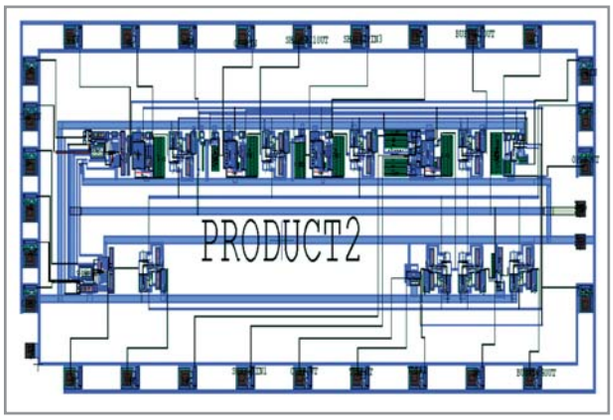
SPAIR (Silicon-strip Pulse Analog Integrated Readout)

SPAIR is a typical nuclear instrumentation pulse-processing channel. It has 16 pulse processing channels & one trigger channel for generating level one trigger in a typical nuclear experiment. Each of the signal-processing channels comprises of charge amplifier, PZ-adjustment, RC-2CR shaping, Track & hold, serial readout & independent output. The channel has provisions for adjusting gain, peaking time, adjustable output polarity and DC offset compensation. The bias control is external so as to control the performance.



CODA (Co-chip for Dosimetry Applications)

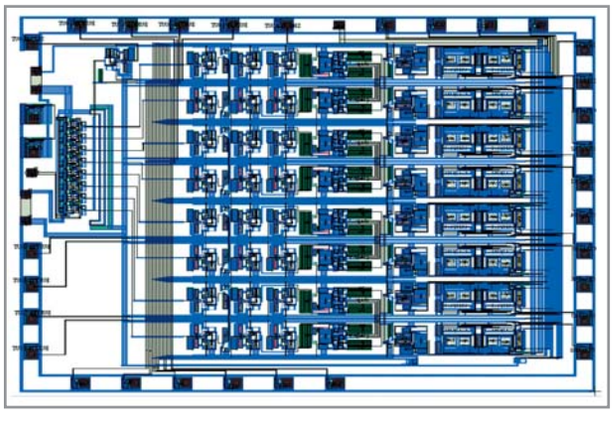
CODA is a low noise single pulse processing channel consisting of charge amplifier, shaper, T&H and Comparator. It is suitable for X/Gamma ray spectroscopy using silicon detectors and it is specifically targeted to Dosimeter & radiation monitoring instrumentation applications. The



design is optimized for low power, high gain & typical dosimeter applications.

MICON (Modified current Converter)

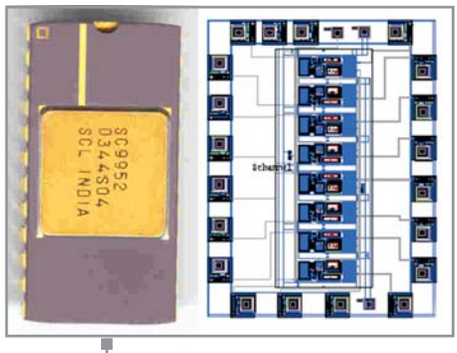
MICON is targeted for very high energy (~150 MeV) applications, e.g. fission fragments in physics experiments. This chip comprises of 16 independent small peaking time pulse processing channels. Each channel comprises of a current amplifier, shaper, track & hold. An analog multiplexer is also included to provide a multiplexed output. The front-end preamplifier module is a current amplifier with



common gate input stage. Leakage compensation scheme has also been incorporated. The module features externally adjustable Gain & output polarity. MICON has 16 channels with shaped output & serial analog read-out incorporating in-built in track & hold. It features external bias management for optimum performance with respect to noise, temperature & process variations during fabrication.

OPREAM (Octal Pre-amplifier)

OPREAM can serve as a front-end pre-amplifier chip for detectors with capacitance up to 50 pf. It is targeted both for counting (e.g. dosimeter) and low energy spectroscopy applications, typically in multi-channel environment. Pre-amplifier is designed with folded cascode configuration for wide bandwidth and high open-loop gain.



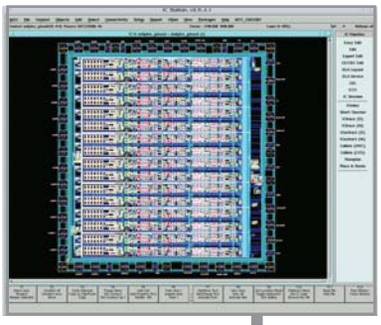
OPREAM Layout

Emphasis is given on low noise and low voltage supply environment. It can take input of either polarity. Preamplifier output fall time can be controlled externally to optimize noise & count rates. Its output stage is capable of driving RG-58 cable. It comprises of eight CMOS low noise charge sensitive amplifiers.

INDIPLEX

INDIPLEX is a 16 channels pulse processor ASIC targeted for gas proportional counters. The design is optimized for the dynamic range of +600 fC to –600 fC with provision for externally adjusted pole-zero cancellation. A dedicated filter based on the de-convolution principle is used for the cancellation of the long hyperbolic signal tail produced by the slow drift of ions, typical in gas proportional with the filter time constants derived from the actual detector input signal shape.

The pole-zero adjustment can be done by external dc voltage to achieve perfect base-line recovery to 1% after 4 µs. The simulated 0pf noise is 380 e^- rms. For the peaking time of 1.2 µs with noise slope of 7 e^-.The gain is 3.4 mv/fC over the entire linear dynamic range with power dissipation of 9 mW/Channel. This design is a modified version of gasplex

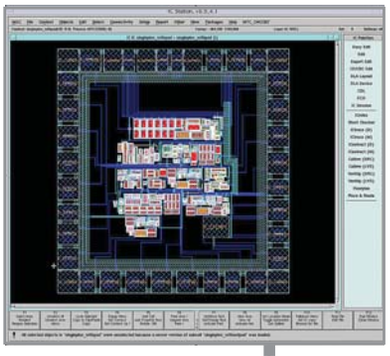


INDIPLEX Layout

chip for enhanced dynamic range, equal gain on both polarities, with nearly same noise.

SINGLEPLEX

SINGLEPLEX is a single channel analog pulse processor ASIC targeted for gas proportional counters / Si detectors. This design is a modified version of INDIPLEX ASIC targeted for use with radiation monitoring instruments.



SINGPLEX Layout

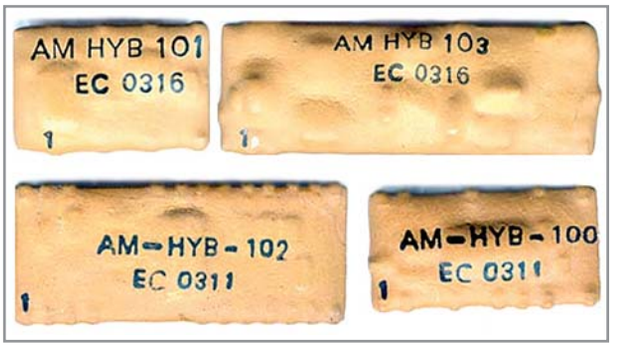
■ Hybrids

Charge Sensitive Preamplifier (1521)

This Hybrid has been developed to provide a charge sensitivity of 45 mV per MeV (Si equivalent) and a rise time of about 25 ns with 100 pf detector capacitance. It is built into a 16 pin hermetically sealed package. A number of preamplifiers using these devices are used by NPD, SSPD and RChD.

High Voltage Hybrids

Four types of hybrids are developed to provide the functionality of Inverter Driver (HYB 101), Voltage Multiplier (HYB 103), Error Amplifier (HYB 102) and Voltage/Current Sense amplifier (HYB 104) in the high voltage supply module. These hybrids are developed in collaboration with ECIL.



Fast Constant Fraction Discriminator Hybrid (CFD): BMC 1550

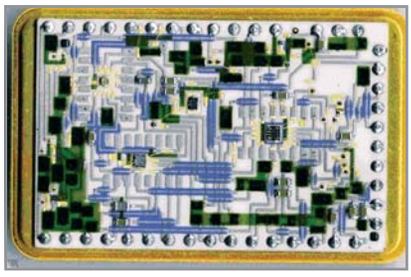
CFD NIM modules with discrete components are being continuously used in Accelerator based multi-detector experiments in BARC and TIFR. As a large number of CFD channels are required in any experiment, CFD circuit has been implemented as a hybrid and fabricated at BEL.

The BMC1550 Constant Fraction 200 MHz Discriminator hybrid accepts negative input signals and generates three

NIM-standard fast negative logic signals for input signal that exceeds the adjusted lower level threshold.

Pulse Pair resolution is 11 ns for input signals with rise time 2.5 ns and the walk is less than <100 psec for a dynamic range of 100:1.

BMC1550 includes independent lower level threshold (-5V minimum) controls to prevent triggering on low level input signals or noise. It has 50 Ohm input impedance and



is protected against overload. A Hex NIM module has been developed using these hybrids.

Pulse Peak Stretcher Hybrid

Peak stretcher is a crucial part of any pulse height analysis circuit. Its performance is an important factor in deciding the linearity of the subsequent ADC and Multi Channel Analyzer.

This hybrid fabricated at ECIL accepts shaped analog input in the range of 0-10 V and needs a flat top of 250 ns min. It has been incorporated in CAMAC Octal ADCs and PCI-MCA-2D in 8 K resolutions, both giving spectroscopy grade linearity with DNL of $< \pm 1\%$.

Time to Amplitude Converter

The hybrid features Start, Stop with reset capability and it gives analog voltage ramp proportional to the time interval between start-stop events. The full scale of 0-5 volts corresponds to 0-500 ns with a resolution of 75 ns. This hybrid has applications in timing spectroscopy and in instrumentation that demands precise time measurement viz. range finder, echo measurement, etc.

Fast Amplifier

The low noise, low power, wide bandwidth (rise time < 2 ns), fast pulse amplifier is developed for applications like fast photon counting applications with high counting rate and photo-multiplier / electron channel multiplier pre-amp/Amplifiers.

The design was simulated, prototyped and given to Bharat Electronics Ltd. (BEL) for fabrication. The hybrid was tested and passed BEL QS qualification. The design incorporates

two-stage complementary pair amplifier with overall voltage series feedback to stabilize gain. The biasing is done to minimize the power dissipation with the required bandwidth. The dc stabilization is done to achieve direct coupling, which is a desirable feature in high-count rate applications.

SPND

SPND amplifier developed using individual ICs with advanced features like on-line detector health monitoring and isolated 4-20 mA current output is now redesigned by using hybrid microcircuit specially designed in view of large volume of usage. This has resulted into improvement in amplifier reliability due to reduction in the number components. SPND HMC, BMC1561, was successfully fabricated at BEL. BMC1561 is packaged in a 32.26 mm square 44-pin metal package with nickel finish.

Ultrasonic Spike Pulser

A Spike Pulser is very commonly used for exciting Ultrasonic transducers used in medical/industrial applications based on Pulse – Echo techniques.

The HMC developed by BARC in collaboration with BEL Bangalore can generate a negative voltage spike with a rise time better than 10 nanoseconds, a pulse width of 100 nanoseconds and amplitude of max. 300 volts. The pulse repetition rate is externally controlled.

Baseline Restorer ASIC and its Applications, P. K. Mukhopadhyay, Prafulla Satish, V. D. Shrivastava and S. Yadav, Y. Rejeena Rani, Y. P. Probhakar Rao, **Proceedings of National Symposium on Nuclear Instrumentation-2004 (NSNI-2004),** pp. 532-534, February 2004

Design and development of Low Power Fast Pulse Amplifier Hybrid Microcircuit for Photon Counting Application, V. B. Chandratre, S. V. Sardesai, R. S. Shastrakar, Vaishali M., P. K. Mukhopadhyay, Prafulla S., Rakesh Mall, Manoj Kori, **Proceedings of National Symposium on Nuclear Instrumentation-2004 (NSNI-2004),** pp. 266-268, February 2004

A Hybrid Charge Sensitive Preamplifier for Nuclear Spectroscopy Applications", V. D. Shrivastava, P. K. Mukhopadhyay, Manoj Kumar Kori, Rakesh Mall and S. K. Sharma, **Proceedings of National Symposium on Nuclear Instrumentation-2004 (NSNI-2004),** pp. 12-15, February 2004

Hex Fast Amplifier and Quad Timing Filter Amplifier Based on Hybrid Fast Pulse Amplifier, Prafulla Satish, P. K. Mukhopadhyay and G. Joshi **Proceedings of National Symposium on Nuclear Instrumentation-2004 (NSNI-2004),** pp. 344-346, February 2004

Design of CMOS Wilkinson ADC, V. B. Chandratre, Asif Iqbal, Menka Tewani and S. K. Kataria **Proceedings of the DAE-BRNS Symposium on Compact Nuclear Instruments and Radiation Detectors (CNIRD-2005)** pp.160-165, March 2005

Design and Development of Pocket Dosimeter using ADAM ASIC and Triplex LCD" Gopalakrishnan N, R. S. Shastrakar, V. B. Chandratre, S. K. Kataria, **Proceedings of the DAE-BRNS Symposium on Compact Nuclear Instruments and Radiation Detectors (CNIRD-2005)** pp.166-169, March 2005

Single Channel Analog Pulse Processor ASIC for Gas Proportional Counters and SI Detectors, V. B. Chandratre, Soumen Sarkar, S. K. Kataria, Y. P. Viyogi, **Proceedings of the DAE-BRNS Symposium on Compact Nuclear Instruments and Radiation Detectors (CNIRD-2005)** pp.170-174, March 2005

Design of Constant Fraction Discriminator ASIC with Large Dynamic Range, V. D. Shrivastava, Prafulla S., S. Krishnan, P. K. Mukhopadhyay, Rejeena Rani, Y. P. Prabhakara Rao, Yogeendra B. N., N. R. Ramesh, S. Kal, **Proceedings of the DAE-BRNS Symposium on Compact Nuclear Instruments and Radiation Detectors (CNIRD-2005)** pp.182-185, March 2005

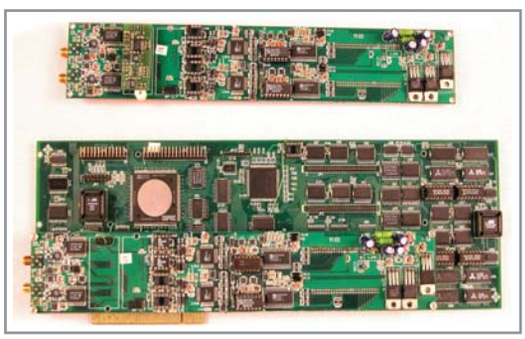
P.K. Mukhopadhyay <pkmuk@barc.gov.in>,

V.B. Chandratre <eld03@barc.gov.in>

6.4 ADVANCED MULTICHANNEL ACOUSTIC EMISSION ANALYSIS SYSTEM (AEA)

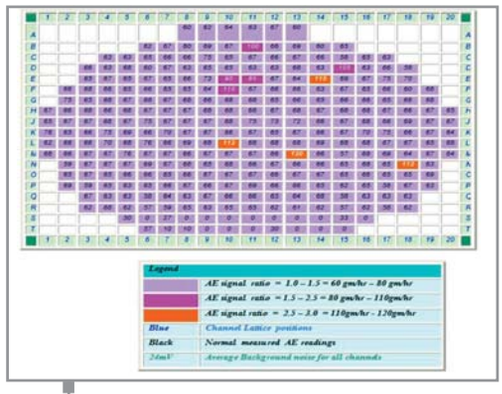
Any typical Acoustic Emission Instrumentation consists of Piezoelectric Sensor, Preamplifier (low noise & high gain) and a Multichannel Data Acquisition, Processing and Analysis Unit.

System features: The PCI based system has advantages of open architecture, modularity, expandability and high throughput. The Four Channel Acoustic Emission Data Acquisition (AEDAQ) card in the system consists of Input section which has programmable gain and band-pass filters, High speed ADCs – 14-bit, 10MSPS sampling rate, FPGAs – for AE Feature Extraction and DSP - for simultaneous acquisition and analysis of AE Features and Waveforms from



Four Channels. The Windows based software acquires, stores and displays AE Parameter and waveform data concurrently in textual and graphical formats. Multiple graphs are displayed in multiple tabbed windows. Data can be processed and analyzed offline using filtering, clustering etc. Location of AE Source can be determined for linear and planar geometries.

A Multichannel AE System



Simplified Sorted Seal Plug Leakage Distribution Bands of KAPS-2

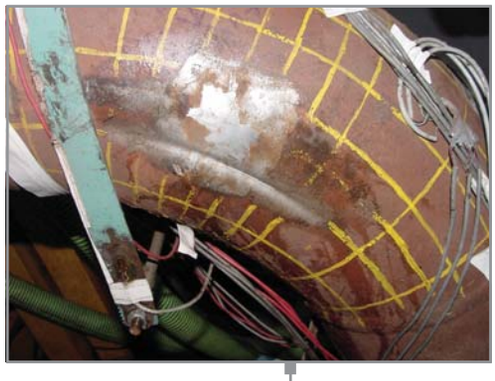
Seal Plug Leakage Monitoring System

Pressurised Heavy Water Reactors (PHWRs) are based on coolant channels concept and consists of 306 numbers coolant channels for 220 MWe PHWR. Seal-plugs are used to close the coolant channels at both ends. Coolant Channels are at high temp & high pressure. They provide radioactive boundary integrity. Any leakages will cause leakage of scarce heavy water, Economic penalty & Tritium hazard. A seal plug leakage monitoring system using AE-Technique has been developed at BARC. After detailed study and experimentation, the developed system has been customized for sorting D_2O leakage from seal plugs of coolant channels of Indian pressurized heavy water reactors. The system was used to detect leaky seal plugs at KAPS-2 and NAPS-2.

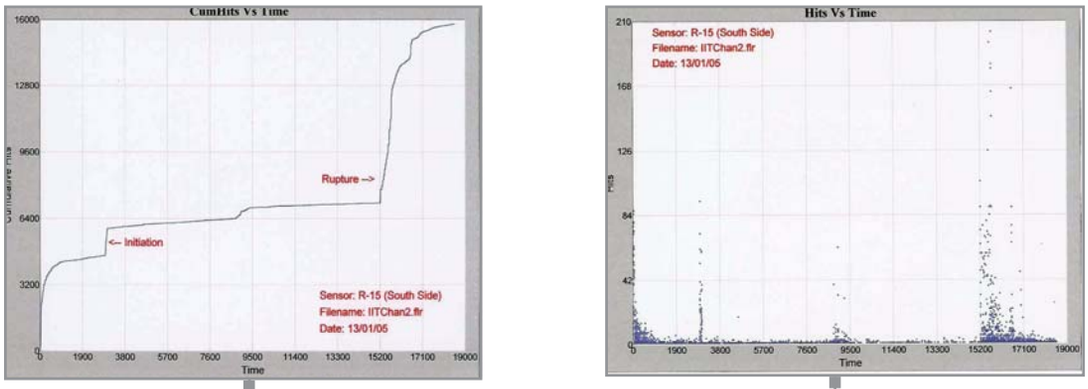
Detection of Crack Initiation and Propagation during Ratcheting Test on PHT Piping Elbows at SITAC

Ratcheting is a phenomenon whereby strain accumulation takes place under cyclic loads. After certain cycles strain accumulation stops which is called as shakedown. Five Ratcheting Tests on Elbow Pipe Components of PHWRs have been carried out by BARC at Structural Integrity Testing and Analysis Center (SITAC) in IIT Powai. As Acoustic Emission Technique (AET) is a very sensitive NDT technique, an AE System indigenously developed at BARC has been used to Monitor Crack Initiation and Propagation during these tests.

Cyclic Displacement Load with different frequency and load was applied to the sample while maintaining constant internal water pressure of 300 Bars. AE signals were captured and graphs of various parameters were plotted. From all of the graphs it is observed that, there was a sudden increase



Experimental Setup for Detection of Crack Initiation



Experimental Results for PHT Elbow

in the AE activity during Crack initiation, Crack Propagation and Rupture. The Crack initiation was observed between 23rd to 28th cycles.

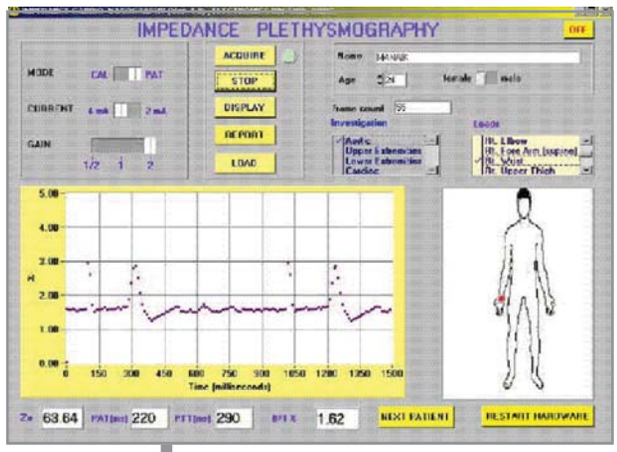
H. R. Mehta <mehtahr@barc.gov.in>

6.5 BIOMEDICAL INSTRUMENTATION

Development of Biomedical instruments -both nuclear as well as conventional types- has been carried out at BARC since last forty years. Earlier significant developments include Thyroid uptake monitors, Renogram, Slow and Fast Nuclear Scanners, Electromyograph and Physiological stimulators. Since last 2 decades, instruments based on variation of electrical impedance consequent to blood flow have been successfully developed. Primarily, these are low cost and non-invasive substitutes to expensive and invasive alternative systems. A societal need of our country is the driving force behind these developments. Some recent developments are briefly described below:

■ Impedance Cardiovasograph

With the help of this instrument, a constant, high frequency current is passed through the desired body segment. Pulsatile changes in the electrical impedance of the segment are sensed, amplified and processed using a personal computer. The technology of this instrument has been transferred to M/s. Larsen & Toubro Ltd., Mumbai.



Operator Panel of ICVG System

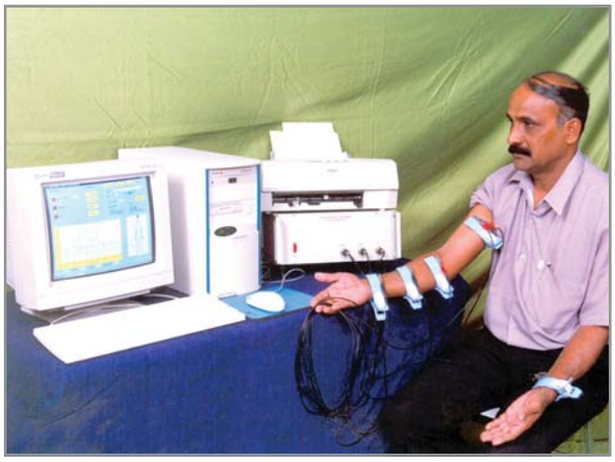
■ Cardiac Output Monitor

Cardiac Output – which is the total volume of blood pumped by the heart in one minute, is a very important parameter

for critically ill patients such as those in ICUs and ICCUs. Conventional techniques used for determining cardiac output are invasive and expensive. The cardiac output monitor enables estimation of cardiac output non-invasively by sensing variations in electrical impedance in cardiac regions. This instrument can also be used as a part of ICCU instrumentation. The technology for this instrument has been transferred to M/s. Larsen & Toubro, Mumbai.

Medical Analyzer

It is known since long that a lot of useful and diagnostically important information is dormant in the variations of physiological parameters like ECG, pulse etc. A unique system, capable of recording variability in heart rate, respiration rate, cardiac output etc. has been developed. Initial clinical evaluation has shown that the variability spectrum shows



distinct changes in the disease conditions like hyper / hypo thyroidism, liver cirrhosis, diabetes, tuberculosis etc. Detailed study of Ayurvedic *naddi pariksha* and pharmaco dynamics of homeopathic medicines is underway

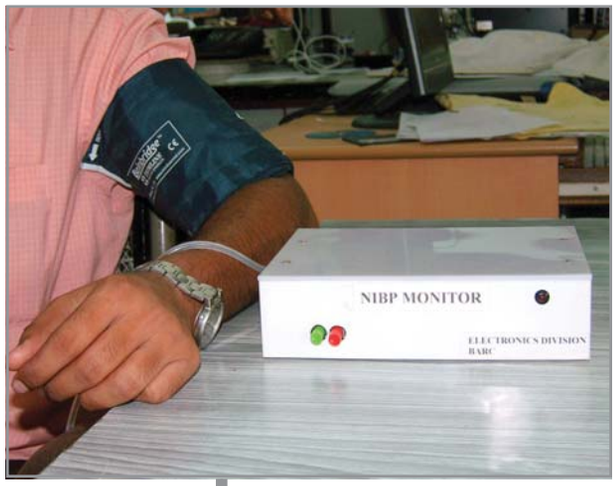
Anu-Photo Rheograph

This instrument is based on photo transmission plethysmography. It employs an infrared transmitter and photo detector, which are mounted on the index finger or toe of a person. Signals from photo receiver are processed to obtain rate of change of blood volume. The instrument can be interfaced to PC for information display/analysis.

Anu-Photo Rheograph

NIBP Monitor

Non-invasive monitoring of arterial Blood Pressure is extremely important for patients in ICCUs. The Non-Invasive Blood Pressure (NIBP) monitor uses oscillometric method for measurement of Blood Pressure non-invasively. It uses changes in pressure (dp/dt) during inflation to derive mean, systolic and diastolic pressures.



NIBP Monitor

Oxygen Saturation Monitor

Conventional instruments used for blood gas monitoring, which is highly essential for patients with cardio respiratory complications, are invasive. The non-invasive oxygen saturation monitor developed recently employs red Light Emitting Diode (LED) as well as Infra Red LED and suitable photo detectors mounted on the finger tip of the patient.

The output of the photo detectors is processed to obtain blood volume changes to determine oxygen saturation percentage. After successful initial trials, a detailed clinical evaluation is being carried out.

SPO2 Monitor

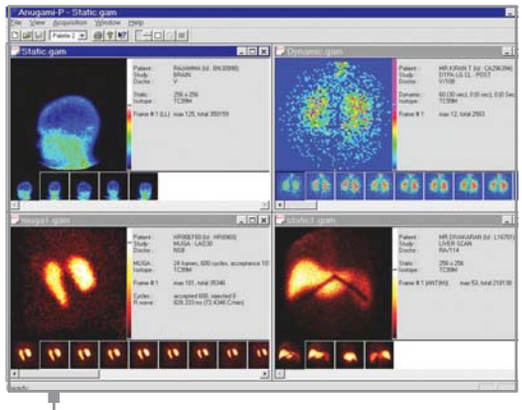
Anugami-P-Gamma Camera Data Acquisition System

Gamma Cameras are widely used to study the functioning of various organs in a human body. Gamma emitting radioisotopes are administered to a patient in the form of a radiopharmaceutical. While the radiopharmaceutical is processed in human body, the gamma rays are detected by the photo-multiplier tube (PMT) assembly and associated electronics. Anugami-P consists of a PC add-on card interfaced to the camera and the Windows based image acquisition and clinical analysis software for PC. The quality of images is improved by applying corrections to remove the artifacts. By replacing the obsolete computer systems with low cost PC based systems, Anugami has significantly extended the useful life of old Gamma Cameras.

Anugami-P Gamma Camera Interface Card

The Anugami-P interface card accepts x, y position signals, z energy signal and ECG pulse along with synchronizing signal.

Anugami-P supports different modes of operation. The Static mode is useful for obtaining a single snapshot from the Gamma camera. Typically the bone scan of cancer patients is acquired in Static mode. The Dynamic mode is useful for acquiring a sequence of frames to study the rate of flow, the rate of uptake or the rate of clearing of the radiopharmaceutical. Typically the renal studies of the kidneys are carried out in Dynamic mode. In MUGA mode, acquisition of frames is synchronized with the heartbeats. In SPECT mode, the Gamma camera head is rotated and frames are acquired at different positions. These frames are then processed with a back projection algorithm to reconstruct a 3-D image. Images can be saved to the disk in different file formats. Like DICOM and INTERFILE. Recently three gamma cameras were upgraded with Anugami-P, one each at MDOCTRF in Ludhiana, SNMC in Agra and RRMC in Kolkata.



Anugami-P Image Acquisition Software

Objective Monitoring of Response of Homeopathic Medicines using Medical Analyzer, G.D. Jindal, T.S. Ananthakrishnan, S.K. Kataria, Vineet Sinha, R.K. Jain, Mousami A. Naik, Electronics Division, BARC and Alaka K. Deshpande, Dept. of Medicine, J.J. Hospital, Mumbai. **BARC External Report BARC/2004/ E/021** (2004)

Anu-Photo Rheography for applications in Clinical Medicine, Sadhana A. Mandlik, G.D. Jindal, T.S. Ananthakrishnan, S.K. Kataria, Vineet Sinha, R.K. Jain, S.K. Singh and A.R. Kini, **BARC External Report BARC/2004/ E/024** (2004)

Electrical Impedance and Photo Plethysmography for Medical Applications, G.D. Jindal, T.S. Ananthakrishnan, S.K. Kataria, Vineet Sinha, R.K. Jain, Sadhana A. Mandlik, A.R. Kini, Mousami A. Naik, S.K. Singh, S.H. Sanghvi* & G. Haridasan*, Electronics Division, BARC and Alaka. K. Deshpande & Ujjawala A. Mahajan, Department of Medicine, J.J. Hospital, **BARC External Report BARC/2004 /E/025** (2004)

An introduction to Impedance Cardiovasography, Dr. G.D. Jindal, **Proceedings of National Workshop on Non-Invasive Measurement of Peripheral Blood Flow and Cardiac Output,** February, 2005.

Dr. G.D. Jindal <jindal@barc.gov.in>

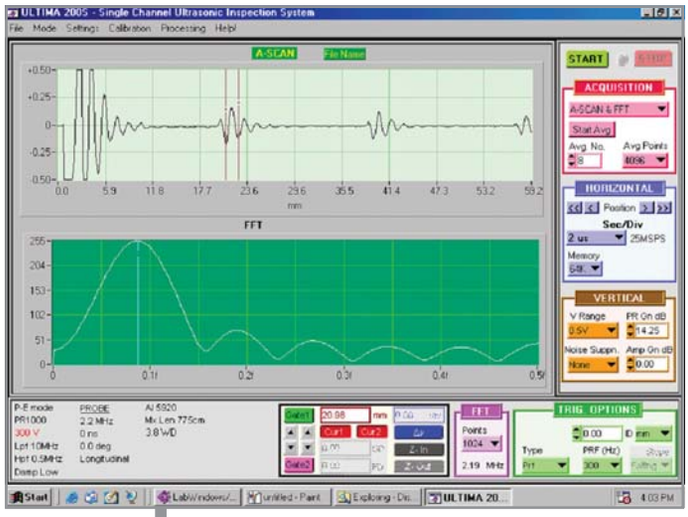
6.6 ULTRASONIC INSTRUMENTATION

'Ultrasonic Imaging' enables a detailed visualization of the interiors of mechanical assembly parts. When placed at one location along an accessible surface of such an object, the ultrasonic transducer indicates the presence of material discontinuities located along its 'line of sight'. The display of the resultant waveform is known as 'A-Scan'. By moving the transducer in a calibrated manner, it is possible to generate a cross sectional image known as a 'B-Scan'. Typical electronics hardware of such a system includes a) Suitable transducer/s, b) An Ultrasonic Pulser/ Receiver unit, c) A high speed digitizer for digitization and storage of echo signals, d) An application based mechanical scanner for controlled & calibrated movement /positioning of the transducer and e) A host computer such as a personal computer for scanner control, data acquisition & processing and information display. Suitable software employing a Graphical User Interface (GUI) is also needed for user friendly operation. Two types of systems viz. ULTIMA 200S (Single channel) and ULTIMA 200M (Multi-channel) are developed for imaging and inspection of industrial components. Several such systems have been fabricated and supplied to various users in DAE.

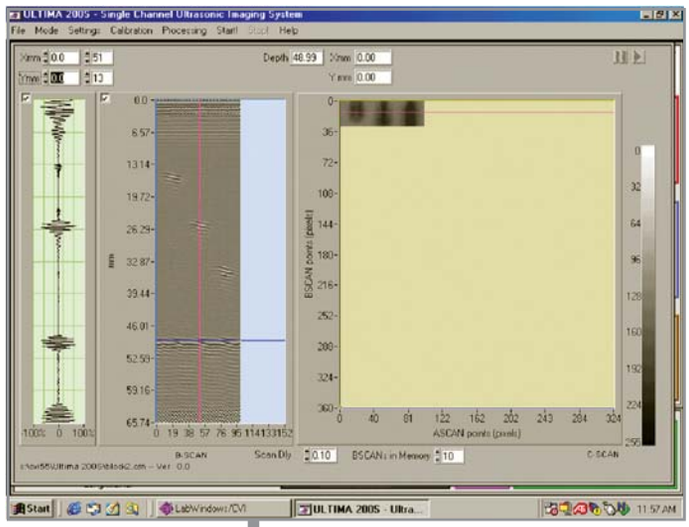
ULTIMA 200S

ULTIMA 200S is an Industrial PC based single channel Ultrasonic Imaging system that uses a single transducer operating in Pulse/Echo mode or a pair of identical transducers operating in Transmit/Receive Mode. Salient features of ULTIMA 200S are:

- ISA bus compatible Pulser/Receiver and Amplifier boards.
- PCI bus compatible 200 Million samples per second (MSPS) Digitizer board.
- GUI based dedicated applications software for data acquisition & processing, information display, scanner status indication, and scanner-control.
- Display of B Scan image with selectable A Scan.
- Display of C scan image with selectable B scan and A scan data.



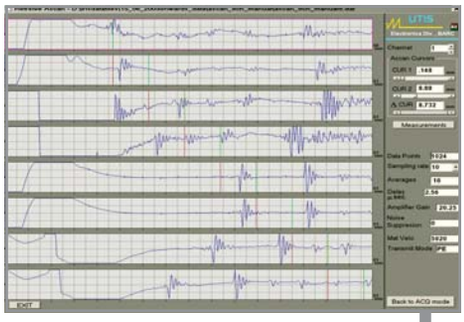
A-scan Waveform with Amplitude Spectrum of the Selected Portion



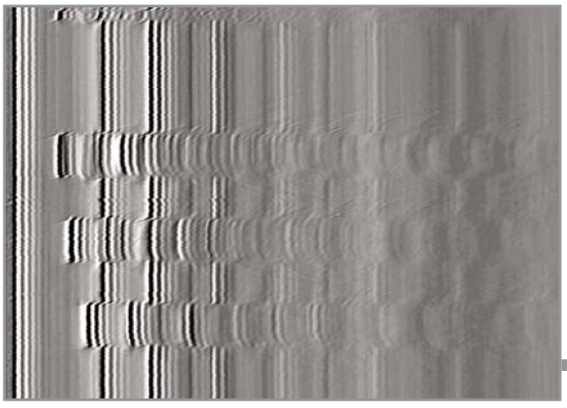
The GUI for ULTIMA with A-scan Waveform and B/C–scan Images

ULTIMA 200M

ULTIMA 200M is an Industrial PC based multi-channel Ultrasonic Imaging system that can provide a maximum of 8 channels for transmitting and receiving ultrasound. It retains all the features of single channel system.



Display of Multiple A-scan Waveforms



B-Scan Image Obtained Using Multi-Channel System

8-Channel Ultrasonic Tube Inspection System

Some additional features are:

- An 8 channel sequencer for setting the sequence of transducer excitation and associated multiplexing/ de-multiplexing of signals.
- GUI based Applications software for display of multi-channel information.

PCI Bus based High Speed Digitizer Cards

The High Speed Digitizer board is a very important constituent of an Ultrasonic Imaging system. PCI bus compliant High Speed Digitizer cards have been developed primarily to meet this requirement. However, the design is flexible, thereby, making these cards suitable for other specific/engineering applications also.

Dual Channel 100 MSPS PCI Digitizer

This board provides 2 channels for acquisition of two analog signals. Both the signals can be sampled simultaneously at a maximum sampling speed of 100 MSPS. Provisions are made to interlace the data sampled by two channels so that a single input signal can be digitized at 200 MSPS.

Technical Features:

- Selectable sampling speed.
- Internal/External triggering.
- Display of waveform in Time domain.
- User adjustable cursors for time / amplitude based parameter measurements.
- Display of Amplitude Spectrum of a selected portion of the acquired signal.

500 MSPS PCI Digitizer

Technical Features:

- Single channel data acquisition at a max. Sampling rate of 500 MSPS
- Storage of waveform with all data acquisition parameters
- Extensive use of high speed CPLDs
- Useful for high resolution ultrasonic testing /imaging

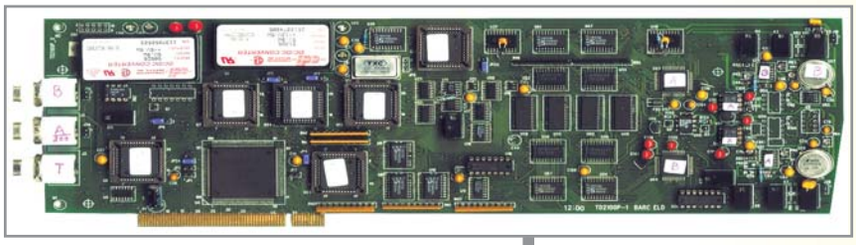
Video Image Capture Board

Image Processing is extensively employed in various scientific or engineering applications. A CCD based video camera serves as a simple and inexpensive means of acquiring images from appliances like microscopes. The video image needs to

be captured before processing. The PCI bus based video capture board is developed for such applications.

Some salient features of this card are:

- NTSC/PAL/SECAM video signal decoding, sampling and storage in PC resources
- Variable image resolution up to 768(H) x 576(V) max
- Y/CB/CR or R/G/B format for color images



TDP 2100P PCI Bus Based 200 MSPS Digitizer

TD1500 – PCI Bus Based 500 MSPS Digitizer

- Grayscale image capture with 8 bits/pixel
- Selectable image size
- Over 100 cards made and supplied to users in DAE

Video Image Capture Card

Design and Development of an Ultrasonic Pulser/Receiver Unit for Non-Destructive Testing of Materials, V. H. Patankar and V. M. Joshi, **BARC External Report BARC/2002/E /034** (2002).

Single channel Ultrasonic Inspection System – ULTIMA 200S, Alok Agashe, P. D. Motiwala, V. H. Patankar, V. M. Joshi, R. K. Jain, and S. K. Kataria, **Abstracts of NDE 2002- National Seminar of ISNT,** December 2002

Development of 4-Channel Ultrasonic Imaging System for Volumetric Inspection of Solid Cylindrical Structures, V. H. Patankar, V. M. Joshi, and S. P. Srivastava, **Journal of Non Destructive Testing & Evaluation** Vol.2, Issue 3, pp. 35-40, December 2003.

Development of Instrumnetation and Automation for NDE Applications: In-house experiences in the Department of Atomic Energy - Part II: Development and Applications of ULTIMA 100+ - An Ultrasonic Imaging System V. M. Joshi and V. H. Patankar,' Insight'-**The Journal of British Institute of Non-Destructive Testing** Vol. 45, No.1, pp. 75-76, January 2003.

PCI Bus Based Video Frame Buffer, S. K. Lalwani, A. A. Agashe, P. D. Motiwala, and V. M. Joshi, **Proceedings of National Symposium on Nuclear Instrumentation-2004 (NSNI-2004),** pp. 532-534, February 2004.

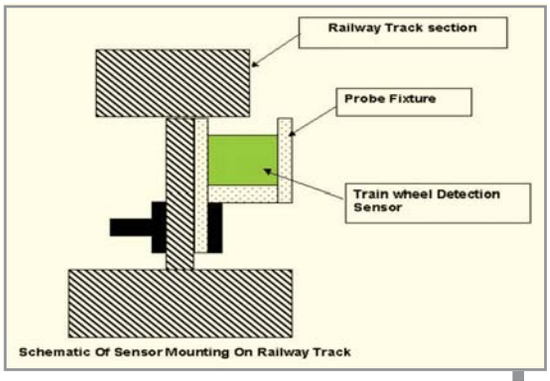
PCI Bus Based 500 MS/s Digitizer, P. D. Motiwala, A. A. Agashe, V. M. Joshi, S. K. Kataria, **Proceedings of National Symposium on Nuclear Instrumentation-2004 (NSNI-2004),** pp. 523-526, February 2004

V.M.Joshi <vmjuis@barc.gov.in>

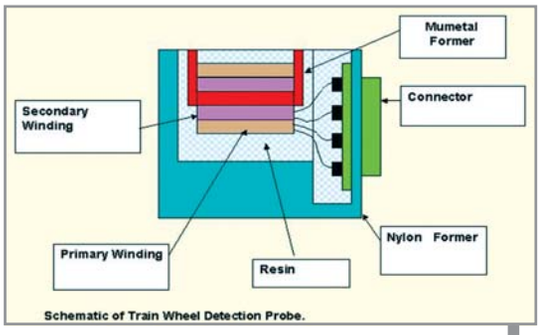
6.7 EDDY CURRENT BASED TRAIN WHEEL DETECTION SENSOR

A non-intrusive train wheel detection sensor has been developed which has the capability to detect wheel axles of train plying at high speed. The sensor is based on the principle of eddy current technique i.e. whenever a ferromagnetic material comes in the vicinity of the probe, the resultant flux increases and induced secondary voltage also increases. The sensor is designed in such a way that it is rugged, hermetically sealed and compact in size. The developed sensor was mounted on the inner side of the mid section of 'I' of the rail track, so that it is safely secured from any hazard of hitting against the rim of the wheel axle or any loose parts hung on the bottom side of the train and as well as from cattle shield.

As the sensor is mounted closely to rail track, which is a ferromagnetic material, it has been devised to have a feature so that whenever the axle wheel rim comes over the top of the sensor the secondary voltage pickup crosses the threshold setting and triggers the comparator.

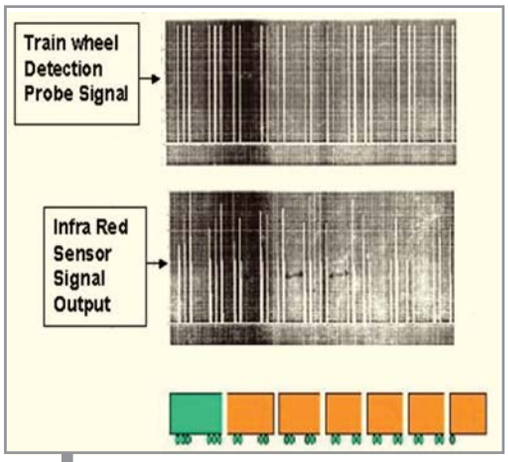


Schematic of Sensor Mounting on Railway Track

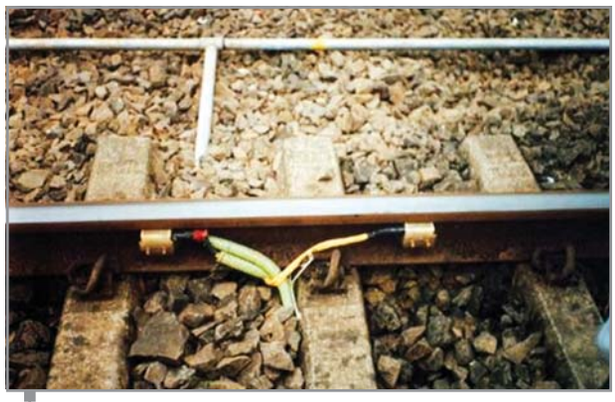


Schematic of Train Wheel Detection Probe

The sensor has been incorporated with noise immunity against any electromagnetic as well as electrostatic interference by configuring two probes in differential mode. The input signals are fed to the instrumentation amplifier, filtered and given to comparator to convert it into bi-level signals. The comparator gives a train of high output pulses on axle coming over the sensor. The dynamic detection has been attained by sending the pulses coming from the comparator to the interrupt of the micro-controller, which senses the discrete pulses coming at the excitation frequency rate, and gives a single output pulse per axle. The timer interrupt of the micro-controller has been used to envelope these cluster of pulses as single pulse per axle. The signal output of the developed eddy current train wheel detection system in comparison to infrared system is shown in the figure.



Signal output of intercepted train wheel from the train wheel Detection Probe compared on infrared sensor signal



The Train Wheel Detection Sensor installed at Mangoan Station Railway Track of Konkan Railway

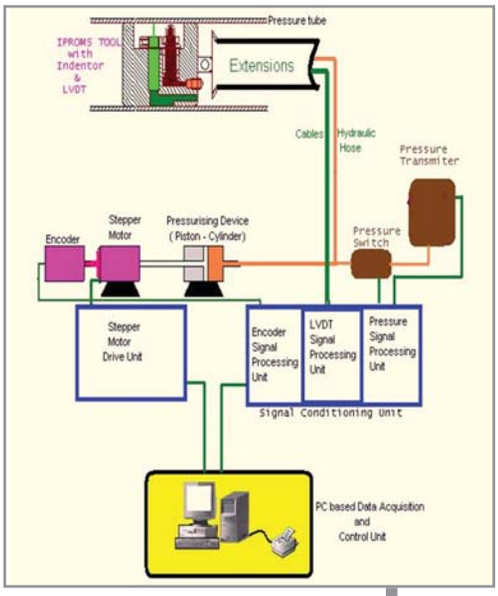
The frequency of excitation of the sensor has been optimized to give maximum sensitivity. The sensor has been operated at a distance of 50 meters cable length. The developed sensor was installed at Mangoan station of Konkan Railway.

T. V. Shyam <redrccs@barc.gov.in>

6.8 IN-SITU PROPERTY MEASUREMENT SYSTEM (IPROMS)

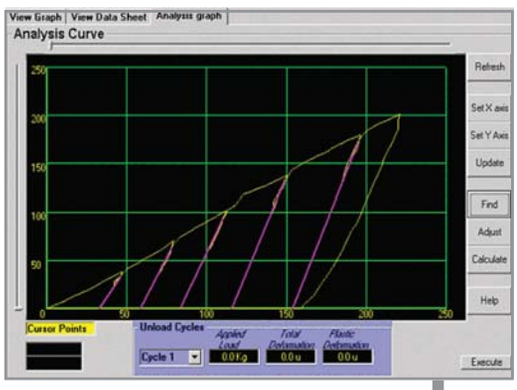
IPROMS will be used to estimate the mechanical properties of reactor components i.e. yield parameter, yield strength, UTS, Brinell hardness of in-situ tubular materials (pressure tube of Indian PHWR) and other non-tubular materials

also. It is based upon the ball indenter movement measurement by a very precise, micron level LVDT.



IPROM Control Schematic

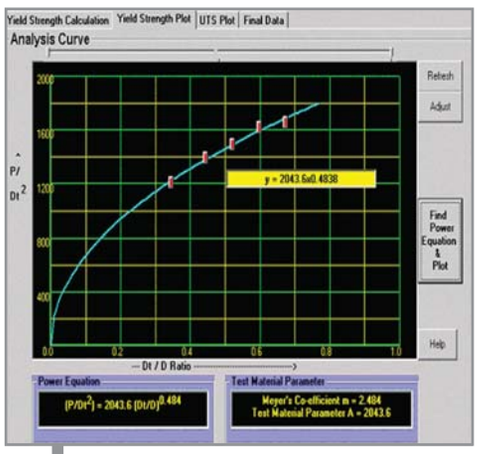
The indenter is moved by means of hydraulic arrangement, which in turn is driven by stepper motor with incremental encoder for feedback. A pressure transmitter in the hydraulic circuit gives the actual pressure applied. A pressure switch is also added in hydraulic circuit to cut off the stepper motor operation. A LVDT mounted along with ball indenter measures deformation of material (under test) caused due to indentation. The LVDT signal output through 100 meters cable is given to LVDT signal processing unit. IPROMS data acquisition software controls the speed / motions of stepper motor based upon the feedback received from shaft encoder and pressure transmitter. The control software and hardware units regulate the motion of stepper motor to acquire predefined number load-unload cycles. The obtained Load-deformation curve using developed analytical model provides various mechanical properties of material under test.



Typical Load- Deformation Curve

■ Data Acquisition & Data Analysis Software

Figures show typical PC screen showing various features of in house developed software viz. Load - Deformation curve, Yield Strength Plot respectively. The salient features of software are Online Data Analysis for property estimation, calculation of True stress, Plastic strain, UTS, Yield strength, Meyer's co-efficient etc.



Yield Strength Plot and Curve Fitting

Data Analysis Code is being used for estimating the material properties of number of test materials.

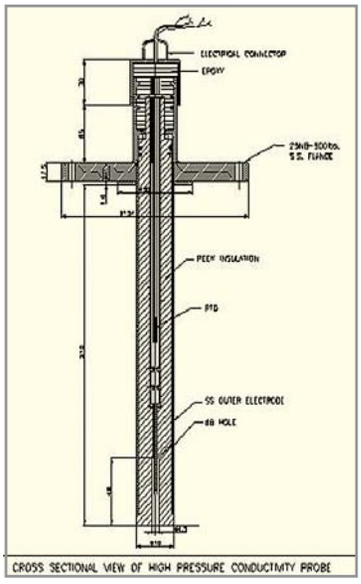
S. Parmar <sparmar@barc.gov.in>

6.9 HIGH PRESSURE CONDUCTIVITY PROBE FOR POISON MODERATOR INTERFACE MOVEMENT IN SDS 2, 540 MWe PHWR

In the Shutdown System 2 (SDS 2) of 540 MWe PHWR, there is no physical barrier between the poison and the moderator.

Their own liquid in liquid interface separates these two fluids. Under normal reactor operation, the poison moderator interface is at the 65 mm NB isolation ball valve in the U-bend region. However, interface moves towards Calandria over a period of time due to molecular diffusion and also due to physical disturbance in moderator level.

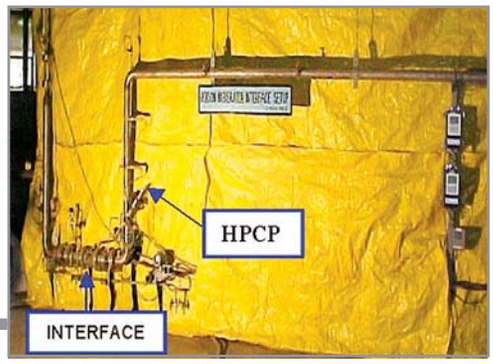
In order to monitor the poison moderator interface (PMI) movement, two online 'high-pressure conductivity probes' (HPCP) are used. On interface movement towards Calandria, there is increase in conductivity and at safe value annunciation is made. To bring the interface back to its normal location, migrated poison is removed by draining.



It was found that the online conductivity probes for industrial application are available for maximum 35 bar pressure with threaded connection in PVC or metallic body. In order to meet the SDS-2 requirement of 80 bar rated probe, a developmental program for high-pressure conductivity probe was taken up and two numbers of temperature compensated online high-pressure conductivity probes were developed.

Some of the salient features of these probes are as follows.

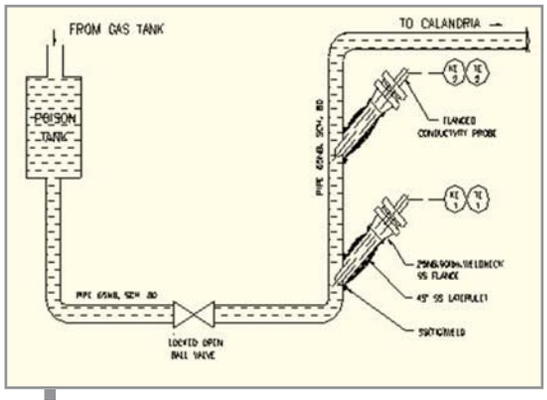
- Suitable for operating pressure up to 85 bar. (hydro tested at pressure 150 bar). Built-in temperature sensor (RTD) for automatic temperature compensation.



HPCP Installed at Full Scale Poison Moderator Interface (PMI) Exp. Setup

- Material compatibility for heavy water application.
- Probe length to suit 65 NB vertical pipeline installation with 900 lbs rating, 45 degree latrolet and 1" size, SS weld neck flange connection.
- Probe diameter to introduce least resistance in poison flow path and designed to sustain the high poison velocity of 25 m/sec during injection.
- With overall measurement accuracy ±1.0%.

Above picture shows a high-pressure conductivity probe (HPCP) used at full scale poison moderator interface (PMI) setup at Hall diffusion data for Tarapur Atomic Power Plant (TAPP 4). The probe is used with a precision digital conductivity meter. Various tests such as primary calibration, stability test, hydro test, response test, process pressure variation effect, online temperature compensation test, flow induced drag force test at 60 and 80 bar pressure, were conducted on developed probes to qualify the same for reactor application.



HPCP Installation scheme for SDS 2 of TAPP 4

Based upon experimental results, installation scheme for two number of high-pressure conductivity probes (HPCP) was worked out for SDS 2 of 540 MWe PHWR. Through vender development programme these probes have been manufactured in bulk and have been installed and commissioned at TAPP 4.

M. K. Sapra <sapramk@barc.gov.in>

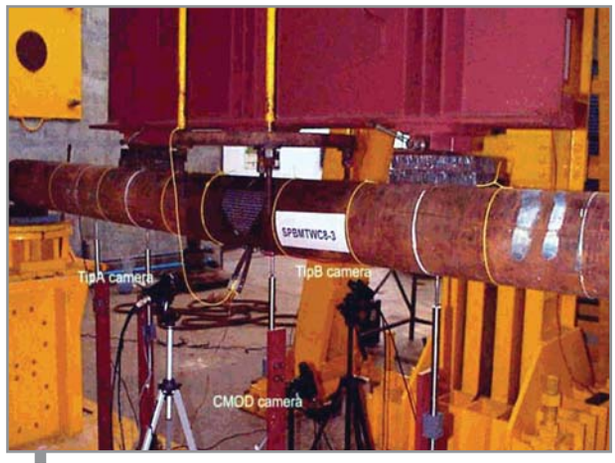
6.10 DSP BASED VIBRATION MONITORING AND PROTECTION SYSTEM FOR HEAVY MACHINERY

A DSP based Vibration Monitoring and Protection System for Heavy Machinery is being developed at Reactor Control Division for ECIL. For this system, DSP based programmable Machinery Protection Board (MPB), I/O board, Relay Output board and back panels as per API (American Petroleum Institute) Standard 670 are being designed and developed. I/O board provides power to four different types of vibration sensors, provides isolation, accepts 4 vibration signals and two-tacho/key phasor signals and performs signal conditioning. MPB acquires the vibration signals, converts these to digital signals, provides fourth order FIR/IIR filters, evaluates peak and RMS values, generates alarm if signal crosses operator set threshold limit, and communicates on Ethernet to PC console for receiving configuration information and transmitting system information. Design of various hardware boards and development of software for the system is in progress.

C. K. Pithawa <pithawa@barc.gov.in>

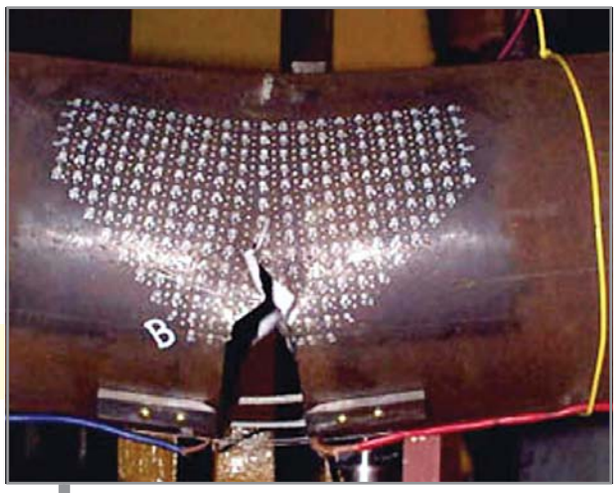
6.11 IMAGE PROCESSING SYSTEM FOR FRACTURE EXPERIMENTS

Computer Division is engaged in the development of vision systems for various scientific and engineering applications. These systems are being used by many divisions of BARC, NFC, IGCAR and other national institutes. A Novel technique based on image processing was developed for the purpose of monitoring various crack parameters during the fracture experiments of piping components in Indian PHWRs. This system was developed and installed at SERC, Chennai. It was



Imaging Set-up for Fracture Experiments to Monitor Crack Growth and Crack Mouth Opening Displacement Installed at S.E.R.C., Chennai

extensively used by Reactor Safety Division with support from computer division to carry out a large number of fracture tests and fatigue tests on various sizes of pipes and elbows



Out-of-plane Crack Growth on 8" Carbon Steel Pipe during Fracture Experiment

and helped significantly to achieve the desired goal in the Component Integrity Test Program. One more system was installed at IIT, Mumbai for carrying out the Ratcheting tests on elbows.