



Working Material

Report of the Technical Meeting (F1-TM-1805383) on

Data Acquisition Systems Used for Nuclear Instrumentation at Particle Accelerator Facilities

Organized and hosted by
The International Atomic Energy Agency (IAEA)

Room C0237, IAEA Headquarters, Vienna, Austria

26-30 May 2019

Scientific Secretary: Mr Natko Skukan, NSIL/Physics - NAPC

Chairperson: Mr Peter Michael Jones (South Africa)

Rapporteur(s): Mr Christian Kwasi Nuviadenu (Ghana)
Mr Stan Lucian (Romania)

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Executive summary

The meeting was organized by the IAEA Nuclear Science and Instrumentation Laboratory (NSIL), Physics Section (PS). PS has assisted in the acquisition and the installation of several Particle Accelerators in recent years, along with the addition of new Data Acquisition Systems (DAQs) to serve them. The objectives of this meeting were to highlight, review and discuss the current state of affairs and recent evolutions in the field with respect to both Ion Beam Analysis (IBA) and Nuclear Physics facilities. The identification of issues and problems encountered by the participants in their DAQ development and operation was also an important aspect, as well as receiving feedback and recommendations for future improvements and programs.

The meeting was attended by twenty-one participants from seventeen Member States (MS) (list of participants in Annex 1) who shared their work experiences and knowledge relevant to the scope of the Meeting (agenda in Annex 2). The presentations resulted in technical discussions on:

- The development and operation of DAQs at Ion Beam Analysis facilities
- Frameworks for the control of Ion Accelerators
- The development and operation of DAQs at Nuclear Physics facilities
- Comparisons between digital and analogue DAQs
- Development and operation of software for DAQs and control
- The use of open source and proprietary software and hardware

The participants concluded that the objectives of the meeting were accomplished through the wealth of information exchanged in presentations and discussions. In brief, the participants came to the following conclusions:

- At the end of deliberations, the meeting participants decided to elaborate a TECDOC which will include descriptions of Data Acquisition Systems (DAQs) at various ion beam analysis (IBA) and Nuclear Physics facilities, based mainly on the presentations by the participants. *The write-up is ongoing.*
- It was decided to contact bigger laboratories and invite them to participate in the elaboration of the TECDOC, as they might give a different perspective on DAQs.
- The meeting also assessed the status of DAQs at participating IBA and Nuclear Physics facilities.
- The need for networking with the aim of sharing of experience and knowledge was extensively discussed and ways to carry this out were proposed.
- Important features present in the given presentations have been selected by the meeting participants to be highlighted. The outcome is presented under the “Meeting Highlights”.
- Recommendations were made to the IAEA for consideration.

- The technical meeting was highly appreciated by the participants, as well as IAEA's involvement in the field of Data Acquisition Systems.
- The meeting also discussed the lack of knowledge of the solutions found by companies and researchers from other fields to common problems.

These conclusions resulted in the following recommendations to the IAEA:

- An **online Data Acquisition knowledge hub** has been repeatedly requested by the participants of the meeting in order to meet the need for networking, cooperation and knowledge sharing within the community. This knowledge hub should be **community-driven**, however *technical assistance in setting it up, popularization with other institutes and groups and endorsement from the IAEA would be highly appreciated.*
- Another feature of such a DAQ hub that has been requested would be a **hardware sharing group or free market**, allowing institutes to pass on unused but still functioning hardware modules and devices to other groups that might use them. However, the institutional mechanisms necessary to make such transfers might often be missing or hard to create for certain institutions. It would be recommended, if this hub is developed, that *IAEA support its popularization and also offer the necessary credibility to the programme by facilitating it.*
- It has also been highlighted that there is currently no **benchmark against which electronic DAQ modules should be tested** and which would assist researchers select the most suitable modules for their applications. Characterization is a critical issue for measurements involving differing count rates and metrological environments. Therefore, reviewing, problem signaling and providing recommendations would also be highly appreciated additions to such an initiative. It is recommended that *IAEA, along with the community, help develop such a benchmark.* It is also recommended that this issue should be a discussion point at subsequent DAQ meetings held by IAEA.
- The **training of new users and developers of DAQ systems** and DAQ programmes have also been highlighted as an important need of the community. It is thus recommended that *IAEA organize more such trainings or associate with already existing DAQ schools* (such as those held by CERN) in order to provide training for young researchers or those from new facilities in the field. More advanced courses could also be set-up in order to further improve the knowledge to experienced users.
- It would be recommended for **IAEA**, with the help of researchers, professors and other institutions, to create a **free e-learning platform about DAQ systems** in order to offer public access to relevant introductory and advanced knowledge in the field to anyone interested.
- It is recommended that **a new Technical Meeting should be held in the next 2-4 years** in order to both update the DAQ TECDOC that will be prepared, to check on the progress of the above given recommendations and to reassess the status of the field. **A new CRP**

might also be proposed after releasing the TECDOC, but both its goals and scope are yet to be defined.

At large, the IAEA is recommended to continue the organization of activities (trainings and meetings) on Data Acquisition Systems and Ion Accelerator Control Systems, as well as to support the development of a community-driven information and discussion hub on the topic.



The participants to the Technical Meeting on the Data Acquisition Systems Used for Nuclear Instrumentation at Particle Accelerator Facilities held in May 2019 in a photo taken in the lobby of IAEA.

1. Introduction

Ion Beam Analysis and Nuclear Physics experiments strive to measure and determine relevant physical information for either applied or fundamental research through the use of ion accelerators and radiation detectors. However, the raw detector signals, usually in the form of voltage or charge signals, have to be digitized or processed before they can be recorded in a computer and used to extract the desired physical meaning.

This interfacing between the radiation detectors and the recording computer system is done by the Data Acquisition System, usually composed of a suite of electronic modules and software packages responsible for various tasks in the processing and digitizing of the signals. In some cases, the Data Acquisition System also plays a role in the control and monitoring of the accelerator and detector systems.

During the last decade, demanding nuclear physics experiments and innovative applications have driven unique developments in nuclear instrumentation related primarily to radiation detectors, tagging techniques and data acquisition systems, designed for accelerator-based experiments. In all cases, it was the requirement for accumulating and subsequently processing signals resulting from extremely high counting rates that pushed for significant improvements in nuclear instruments.

Continuously increasing demand for handling large amounts of data within very short processing times (high speed information processing) led to a new generation of powerful electronics for signal processing. In addition, many applications needed to increase the number of channels integrated in electronic devices and improve the energy and time resolutions following acquisition and design specific signal manipulation algorithms. As a result, users developed new devices, many of which are now commercially available. Due to these developments, data acquisition systems have changed drastically over the years.

The recent years have also led to a noticeable movement from analogue systems, which use series of modules to do electronic processing of the signals, towards digital systems, in which the signals from the detectors are directly digitized and then processed using digital algorithms. Similarly, accelerator control solutions are evolving towards distributed systems, in which multiple computer systems operate various aspects of the accelerator while being connected and controlled by a master computer, as opposed to the older philosophy of having a single computer controlling everything.

The Nuclear Science and Instrumentation Laboratory, part of the Physics Section of IAEA, is dedicated to training scientists and engineers from IAEA Member States in nuclear instrumentation involving data acquisition systems. The Nuclear Science and Instrumentation Laboratory helps Member States' laboratories to use and adapt systems according to their needs.

This Technical Meeting focused on the latest trends and developments in data acquisition systems with the objective of disseminating knowledge and experience to scientists from IAEA Member States in the field of nuclear instrumentation.

2. Objectives

The purpose of the Technical Meeting was to technically assess existing state of the art data acquisition instruments and systems used in accelerator-based experiments; to enhance interaction among experts working on technical issues of such systems; to disseminate new knowledge to scientists and engineers from IAEA Member States in the field of nuclear instrumentation; and to document the challenges and needs for future developments in related nuclear instrumentation.

3. Work done

The opening words of the Technical Meeting were given by Mr Ridikas Danas, Head Physics Section IAEA-NA. The Technical Meeting was attended by 21 participants from 17 MSs (Argentina, Croatia, Ghana, India, Iran, Israel, Italy, Lebanon, Poland, Portugal, Romania, Slovakia, South Africa, Spain, Thailand and Ukraine), as well as by staff members from NSIL, IAEA-NA (see List of Participants in Annex 1). The Agenda of the TM (see Annex 2) included individual presentations, discussion sessions and work in subgroups.

The participants of the meeting agreed to elect Mr Peter Michael Jones (South Africa) as the Chairperson, and Mr Christian Kwasi Nuviadenu (Ghana) and Mr Stan Lucian (Romania) as the rapporteurs of the meeting.

The meeting included the presentations from the participants. Each participant summarized results of their work in fields related to the topics covered by the meeting. Abstracts of each presentation are provided in Annex 3.

4. Highlights of the meeting

There is a wide variety of requirements set by each Ion Beam Analysis (IBA) technique, including but not limited to the type and the number of detectors required, broad or focused beam, scanned or chopped beam or time synchronization of all collected data. Analog data acquisition (DAQ) systems are used routinely in IBA techniques. The analog system is influenced by factors such as noise of the nuclear electronic modules, instability, and the ballistic deficit which can degrade the sensibility and resolution of the analysis. Transition from analog to digital technology in IBA provides a number of technical improvements in the spectroscopic performance and enhances the sensitivity and accuracy of analysis. It is found that digital systems are more compact, simpler and cheaper.

A number of presentations touched on comparisons between digital and analogue data acquisition systems for various applications and requirements. Digital spectroscopy provides superior energy resolution, more symmetric peaks and more stability of peak positions compared

to the analog spectroscopy due to the direct sampling of preamplifier signals. As a result of the effective elimination of damaged and distorted signals, the application of digital pulse processing leads to a reduction of the background in the spectra. Another presenter approached the difference in the systems for use in neutron metrology, specifically with respect to the propagation of uncertainty through the two systems and the difference in the respective live and post-acquisition analysis. Comparisons between the two systems are highly important to encourage the migration to digital electronics and to fully understand the losses and gains of doing so.

Pixelated sensors, such as custom or commercial off-the-shelf CMOS imagers, allow the detection of charged particles, photons and (with the addition of conversion layers) of thermal neutrons with high spatial resolution, low noise and spectrographic information. Coincidence in multiple stacked sensors can be used to detect muons and in a magnetic field to estimate their energy. For thermal neutron detection, high efficiency is achieved using gadolinium based conversion layers, whereas boron-10 conversion layers allow separation of gamma contribution in mixed beams.

During the meeting, a trend of in-house development of custom solutions to similar problems became evident. While some labs do require very specific DAQ conditions and machine interfaces, a number of these custom solutions deal with finding workarounds for obsolete or proprietary software that do not offer sufficient flexibility. The efforts for maintaining and upgrading accelerators and detector systems fall upon a community that is sometimes unable to obtain documentation or support from manufacturers. As a result, the research community is transitioning to using and maintaining a number of open-source projects for machine control as well as data acquisition and it is hoped that the industry will respond by adhering to these practices at least in providing some common interfaces. Another direction being taken by some larger laboratories is developing fully customized solutions for digitization or control, in some cases, overlapping with industrial solutions that are not sufficiently flexible.

The control of electrostatic accelerators typically deals with hundreds of signals (analogue and digital) distributed over the entire infrastructure. There is a common trend nowadays to convert from a single computer controlling system to a distributed control system, running on more than one computer. This enables avoiding extensive complicated cabling in favour of accessing modules easily via a common software bus. Moreover, an intercommunication between the accelerator and the experimental machines is desired in order to be able to increase the automatization capabilities for the experiments performed. Hence, a distributed control system is an ideal choice for controlling the electrostatic accelerators.

Two open source main actors have been addressed during this meeting, namely EPICS (Experimental Physics and Industrial Control System) and TANGO (Taco Next Generation Object). Both of them consist of software tools and applications which provide a software infrastructure for use in building distributed control systems. Both of these systems operate on the principle of using Ethernet connected computers for monitoring, feedback and control. In EPICS, this is accomplished using the Channel Access network protocol. EPICS has a tradition in electrostatic accelerator facilities. Nevertheless, in several institutes, TANGO is used for “gluing” together signals from several machines, acting as a middleware in order to expand the original beam experiment control systems. It must be emphasized that these two software

frameworks have undergone no less than one decade of active development, reaching a level of maturity that makes them capable of fulfilling the entire traditional set of requirements.

Examples of the use of TANGO have been presented, explaining how to connect the original control system of the infrastructure to the middleware (TANGO) and, additionally, how to access parameters in order to have them available on other points on the infrastructure and from the experimental station computers. An EPICS-TANGO bridge exists, introducing the ability to use framework-specific software in either control system, independent of which suite the software was originally developed for. The main concepts behind these frameworks are basically the same.

The Ruder Boskovic Institute (RBI) Group presented a flexible data acquisition system (DAQ) which can handle all the typical requirements for the IBA laboratory. The flexibility was achieved by using a FPGA allowing one system to connect and control beam modification devices, such as ion beam chopper and scanner, and simultaneously collect data from multiple detectors. In addition, the presented digital DAQ system is a hybrid that allows NIM ADCs to be interfaced with the system through a multiplexer board and used where preferred. RBI's hybrid DAQ design can be used for direct comparison of the data collected by digital and analog signal processing. The presented DAQ is relatively cheap, multifunctional and upgradable. It enables possible automation of entire acquisition process, remote acquisition and reusability of old electronics.

5. Conclusions

- At the end of deliberations, the meeting participants decided to elaborate a TECDOC which will include descriptions of Data Acquisition Systems (DAQs) at the various ion beam analysis (IBA) and Nuclear Physics facilities, based mainly on the presentations by the participants. *The write-up is ongoing.*
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6. Recommendations to the IAEA

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Annex 1: List of participants

Jose LIPOVETZKY	Argentina	Comision Nacional de Energia Atomica	lipo@cab.cnea.gov.ar
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Annex 2: Meeting agenda

Monday, 27 May		
08:30 – 9:30	Registration	
9:30 – 10:00	Official Opening:	<i>Mr Danas RIDIKAS, Section Head, Physics Section, IAEA-NA</i>
10:00 – 10:15	Brief self-introduction of the participants	
10:15 – 10:30	Organizational arrangements Presentation of the Workshop Agenda, Election of Chairperson and Rapporteurs	<i>Mr Natko SKUKAN NSIL, IAEA- NA</i>
10:30 – 11:00	Coffee Break	
	Session 1: IAEA structure and activities	
11:00 – 11:15	The structure of IAEA and role of NSIL	<i>Mr Natko SKUKAN, NSIL, IAEA-NA</i>
11:15 – 11:45	The NSIL support to DAQ	<i>Mr Mladen BOGOVAC, NSIL, IAEA-NA</i>
	Session 2: Commercial DAQ systems and applications in Ion Beam Analysis	
11:45-12:15	Data acquisition system of Ion Beam Analysis Laboratory in Trnava	<i>Mr Jozef, DOBROVODSKY Faculty of Materials Science and Technology in Trnava, Slovak University of Technology in Bratislava, Slovakia</i>
12:15 – 13:45	Lunch Break	
	Session 2: Commercial DAQ systems and applications in Ion Beam Analysis (cont.)	
13:45 – 14:15	Multi data acquisition systems at Lebanese 1.7 MV Tandem Accelerator	<i>Mr Mohamad ROUMIE Lebanese Atomic Energy Commission, National Council for Scientific Research, Beirut, Lebanon</i>
14:15 – 14:45	IBA measurements of reference materials with the RC43 acquisition system	<i>Mr Christian Kwasi NUVIADENU National Nuclear Research Institute (NNRI), Ghana Atomic Energy Commission (GAEC), Accra, Ghana</i>
14:45 – 15:15	Applying digital data acquisition systems for running IBA experiments	<i>Mr Hossein RAFI-KHEIRI Physics& Accelerators research school, Tehran, Iran</i>
15:15 – 15:45	Coffee break	

	Session 3: Commercial DAQ systems and applications in nuclear physics	
15:45 – 16:15	Design and development of Data Acquisition Systems for Nuclear Physics experiments at Particle Accelerator Facilities	Mr Saju JOY, Bhabha Atomic Research Centre (BARC), Mumbai, India
16:15 – 16:45	Development of a digital data acquisition system for neutron metrology	Ms Chloe SOLE, University of Cape Town, Cape Town, South Africa
16:45 – 17:15	A Readout System with CAEN Digitizer for Clover Detectors with Anti-Compton Shield	Mr Matteo CORBO, CAEN, Italy

Tuesday, 28 May		
	Session 4: In house solutions for Ion Beam Analysis	
09:00 – 09:30	Development of flexible data acquisition and beam control system for accelerator-based experiments	Mr Zdravko SIKETIĆ Ruder Bošković Institute, Zagreb, Croatia
09:30 – 10:00	An integrated MIDAS and LabView based data acquisition, scanning and stage control system for the nuclear microprobe at the Materials Research Department, iThemba LABS.	Mr Caswell PIETERS Instrumentation and Information Technology Department, iThemba LABS, South Africa
10:00 – 10:30	Ethernet data acquisition and control system for ion-beam analysis: the possibilities for reliable and cost-reduced design based on IOT and image processing technologies	Mr Mikhail RYAZANSKIY Bar Ilan Institute for Nanotechnology and Advanced Materials, BINA, Ramat-Gan, Israel
10:30 – 11:00	Coffee break	
	Session 5: In house solutions for nuclear physics experiments	
11:00 – 11:30	Data Acquisition Systems of the IAP NASU Accelerator-Based Analytical Complex	Mr Serhii KRYKLIA Institute of Applied Physics, National Academy of Sciences of Ukraine, Sumy, Ukraine
11:30 – 12:00	Sub-nanosecond spectroscopy with digital electronics	Mr Peter Michael JONES iThemba LABS, South Africa
12:00 – 12:30	Data acquisition systems for the multidetector array RoSphere	Mr Lucian STAN IFIN-HH, Bucharest, Romania
12:30 – 14:00	Lunch Break	
	Session 6: Instrument control and data acquisition	
14:00 – 14:30	Perspectives and first applications of the Tango control system to electrostatic accelerators	Mr Victor Joco CMAM Madrid, Spain
14:30 – 15:00	ATCA/MTCA control and data acquisition platform for accelerator experiments	Mr Jorge ROSA LOPES DE SOUSA Instituto Superior Tecnico, Lisboa, Portugal
15:00 – 15:30	Control system for industrial linear electron accelerator	Mr Zbigniew ZIMEK

		<i>Institute of Nuclear Chemistry and Technology, Warsaw, Poland</i>
15:30 – 16:00	Coffee break	
	Session 7: Detectors and experiments	
16:00 – 16:30	Detection of thermal neutrons using CMOS imagers and neutron induced damage	<i>Mr Jose LIPOVETZKY Comision Nacional de Energia Atomica, Bariloche, Argentina</i>
16:30 – 17:00	Compact detector for high energy lepton/photon spectrometry	<i>Mr Constantin Mihai CUCIUC IFIN-HH, Bucharest, Romania</i>
17:00 – 17:30	Particle Accelerator Facilities and Data Acquisition Systems in Thailand	<i>Penphitcha AMONPATTARATKIT, Synchrotron Light Research Institute <u>and</u> Thawatchart CHULAPAKORN, Thailand Institute of Nuclear Technology, Thailand</i>
20:00 -	Social event	

Wednesday, 29 May	
09:00 – 10:30	Technical Discussion on presentations
10:30 – 10:45	Coffee Break
10:45 – 12:10	Round Table: The role of IAEA in support of MSs
12:10 – 13:30	Lunch Break
	Drafting of Meeting report
13:30 – 14:15	Discussion on report structure and creation of working groups
14:15 – 16:00	Report drafting in groups
16:00 – 16:45	Report drafting in groups

Thursday, 30 May	
09:00 – 10:15	Report drafting in groups
10:15 – 10:30	Coffee Break
10:30 – 12:15	Report drafting in groups
12:15 – 13:45	Lunch Break
13:45 – 14:00	Work in groups
14:00 – 16:00	Final conclusions

Annex 3: Abstracts of participant presentations

Detection of thermal neutrons using CMOS imagers and neutron induced damage

Jose LIPOVETZKY, Argentina, Comision Nacional de Energia Atomica

Thermal Neutrons (TN) are produced in several types of accelerators, including LINACs used in medical or scientific applications, cyclotrons, etc. The detection of these neutrons is of interest not only if they are the key particle of the experiment, but also for radioprotection reasons. This work dealt with the use of CMOS Image Sensors (CIS) for the detection of thermal neutrons. CIS are integrated pixel arrays originally designed for acquiring pictures in consumer electronics. However, their sensitivity to ionizing particles, low noise due to technology scaling and the integration in the same chip of reading and control electronics makes them suitable for the detection of charged particles. The deposition of a conversion layer (CL) sensitive to TN allows the indirect detection of this type of radiation.

1. The use of a CL containing Gd_2O_3 nanoparticles mixed with a photoresine used as a mechanical support was recently proposed. The capture of TN in Gd yields the emission of electrons detected in the CIS. The high capture cross section of Gd combined with the longer range of the electrons emitted by this layer allows a detection efficiency of up to 11%, slightly better than what is achieved using ^{10}B as conversion material. However, the use of Boron-based CL allows discrimination between neutrons and gamma background.

2. Image sensors fabricated in technologies larger than 180 nm usually comprise a pre-metal layer which includes Boron. We have shown that, after trapping of neutrons in the ^{10}B nuclei in the image sensors, the emitted 6Li and alpha particles can cause the displacement of Si atoms in the reverse-biased junctions of the pixel. This displacement damage causes a permanent damage to the pixel, producing a higher dark current than unaffected pixels. This increase in the post irradiation dark currents of the pixels was tested with the Elekta Synergy radiotherapy LINAC using the same gamma dose, but on one detector with the LINAC operated at 6 MV and on another at 15 MV. These values are below and above, respectively, the photonuclear threshold above which thermal neutrons are emitted. The number of pixels with high dark currents significantly increases after thermal neutron irradiation, providing an indirect way to detect thermal neutrons. It is worth noting that, due to the high gamma-ray fluence, the reading of the detectors saturates during the irradiation, meaning that it would not be possible to distinguish the neutrons from the gamma photons during the irradiation time. This difficulty is usually observed in this application with other detectors, and overcame with the use of the displacement damage for neutron flux dosimetry.

Development of flexible data acquisition and a beam control system for accelerator-based experiments

Zdravko SIKETIĆ, Croatia, Ruđer Bošković Institute

The Ruđer Bošković Institute (RBI) accelerator facility consists of two ion beam accelerators, a 6 MV Tandem Van de Graaff and a 1 MV HV Tandetron, capable of producing and delivering accelerated MeV energy ions to 9 existing end-stations. PIXE, TOF-ERDA, RBS, IL, SEI, MeV TOF-SIMS, IBIC and other Ion beam analysis (IBA) techniques are performed routinely depending on the end-user's requirements. The ion beam shape (broad, focused, continuous and chopped), the processing algorithms as well as the type and the number of detectors required vary between various IBA methods. For example, TOF-ERDA and MeV TOF-SIMS measurements are performed in coincidence mode, requiring all of the collected events to be time-stamped and correlated with each other. If a focused ion beam is used for sample imaging (μ -PIXE, μ -RBS, ion implantation), the beam has to be scanned and its position correlated, in time and space, with signals produced in various detectors. For experiments requiring a chopped beam (IBIC or MeV TOF-SIMS), all data relevant to the experiment have to be synchronised with beam deflections.

In order to cover the wide variety of requirements set by each IBA techniques, a flexible data acquisition and control system was developed. The flexibility was achieved by using a Virtex 6 FPGA with custom made FMC daughter boards allowing one system to connect and control beam modification devices, such as ion beam optics elements, and simultaneously collect data from multiple detectors. The reprogrammable nature of the FPGA was taken advantage of to give the acquisition system the ability to adapt to the experimental conditions set by the user. Once the user sets the parameters, the FPGA reprograms itself in the background without any additional user input. Additionally, an operating system can be run on the FPGA allowing for further integration into a larger system by the implementation of TANGO or EPICS.

IBA measurements of reference materials with the RC43 acquisition system

Christian Kwasi NUVIADENU, Ghana, National Nuclear Research Institute,
Ghana Atomic Energy Commission

Ghana has acquired and installed, with the help of the international Atomic Energy Agency (IAEA), a 1.7MV Pelletron Accelerator at the Ghana Atomic Energy Commission (GAEC). The accelerator end-station is equipped with an RC43® acquisition system, which is also responsible for part of the high-energy beamline and target-chamber operations as well as sample manipulation and data acquisition. As part of performance assessment, the RC43 acquisition system was used to analyse selected standard reference materials using the PIXE, NRA, RBS and ERD techniques at various proton and alpha beam energies. The results were generally within $\pm 10\%$ of the reference values. A few challenges with current integration and sample surface scanning during data acquisition were encountered and discussions are ongoing to resolve them.

Design and development of Data Acquisition Systems for Nuclear Physics experiments at Particle Accelerator Facilities

Saju JOY, India, Bhabha Atomic Research Centre

The frontend Nuclear Instrumentation for an accelerator-based experiment consists of pre-amplifiers, shaping amplifiers, discriminators, high-resolution nuclear Analog to Digital Converters (ADC), Time to Digital Converters (TDC), Charge to Digital Converters (QDC) and multiplicity coincidence-based trigger units. PC-CAMAC data acquisition systems consisting of ADCs, TDCs, trigger units and controllers have been developed and are in use in India for more than a decade now. Maximum throughput achieved with this system limited the maximum event rates. With the advent of the LINAC booster at TIFR Mumbai, a data acquisition system with a throughput higher by an order of magnitude than the existing dual-crate system was needed. The FERA (Fast Encoded Readout ADC) Data Acquisition System has been developed to cater to these requirements, keeping compatibility with existing installed CAMAC setups. Quad FERA ADC, TDC and PCI readout controllers have been developed for these system with additional merits of built-in zero suppression and support for multiple crates without additional hardware for event synchronization.

With the availability of very fast flash ADCs and high-density FPGAs, it is now possible to design digital data acquisition systems in which the A/D conversions occur as close as possible to the detector followed by pulse processing in the FPGA. These will replace the analog nuclear pulse processing electronics for shaper, discriminators, ADCs and TDCs. Modules for a new data acquisition system have been developed using high speed digitization and new techniques such as analog memory ASIC-based delay elements, various shaping and discriminator algorithms, timing filtering and its FPGA-based implementation targeted for high-throughput accelerator-based large experiments.

This presentation briefly covered the conventional CAMAC and FERA-based nuclear pulse processing modules and data acquisition systems used in the accelerator facilities and the techniques and architecture of the new data acquisition system.

Applying Digital Data Acquisition Systems for Running IBA Experiments

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Analog data acquisition systems are routinely used in Ion Beam Analysis (IBA) techniques. However, analog spectroscopy is influenced by the noise of the nuclear electronics modules and detector itself, high dead time, and ballistic deficit which ultimately degrade the analysis performance. To resolve these problems, analogue technology is replaced by Digital Pulse Processing (DPP) technology. This transition provides technical improvements in the spectrometry performance and delivers data with a higher degree of accuracy to support the IBA techniques.

In this work, Particle-Induced Gamma Emission (PIGE) analysis was performed using analog and digital data acquisition systems and the results are compared. The digital setup was based on a CAEN DT5724B digitizer with 14-bit resolution and 100 MS/s sampling rate. The differentiated signal from the preamplifier is directly digitized.

In summary, significant advantages of Digital Pulse Processing compared to the conventional analog signal processing include:

- Higher-resolution energy spectroscopy is possible thanks to noise reduction due to direct sampling of the detector signals.
- Long term stability of the peak position due to the elimination of amplifier gain variations.
- Reduction of peak asymmetry by effective elimination of the ballistic deficit via optimum selection of flat top time duration of the trapezoidal filter.

Ethernet data acquisition and control system for ion-beam analysis

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Accelerator control and data acquisition systems are traditionally realized as a complex combination of a wide set of data interfaces: RS422, USB, Ethernet, and a lot of analog and digital inputs and outputs, connected by proprietary interface boards and boxes with specific drivers and software. This design is usually complex to manage, improve or repair, and is often unreliable. Nowadays, a huge assortment of cheap Ethernet and WiFi-controlled devices are developed and mass-produced for the “Internet of Things” (IoT) – these can be easily used, but are similarly unreliable.

We propose the implementation of a simple architecture for control and data acquisition, based on Ethernet (with different transmission media) and IP protocols, and on redundant sets of cheap IOT controllers and web-cameras. Moreover, many complex sensors can be simplified by using real-time processing of web-camera images (precise target and beam positioning, determination of beam parameters and stability, logging the measurements from devices originally not connectable to computer). Several examples of technical realizations were presented.

The main advantages are: better possibility for fast and inexpensive instrument improvement; increasing of total performance and reliability, reducing of instrumental errors (using similar data collected by multiple separated channels); good separation between the hardware and software development and improvement; extended opportunities for task automation, measurements standardization and data logging; reducing the cost and increasing the portability of equipment.

A readout system with CAEN digitizer for Clover detectors with anti-compton shield

Matteo CORBO, *Italy, CAEN*

Clover High-Purity Germanium (HPGe) detectors are having more and more success in low and medium energy nuclear physics applications dedicated to gamma-ray spectroscopy. These detectors consist of 4 coaxial N-type High Purity Germanium (HPGe) crystals. Each crystal is specially shaped to be mounted in a common cryostat to form a structure resembling a four-leaf clover. These detectors are surrounded by scintillators like BGO or CsI, which are used to reject gamma radiation interacting through Compton effect, scattering inside the germanium crystals and then escaping from the active volume.

The presentation describes in detail a Clover readout system solution based on the innovative approach based on fast and high resolution waveform digitizers. Electronics, firmware and Data Acquisition (DAQ) software infrastructure are described. Experimental results achieved in a real use case are also reported, taken with the experimental setup built at the DHRUVA reactor facility at BARC (India).

Multi data acquisition systems at Lebanese 1.7 MV Tandem Accelerator

Mohamad ROUMIE, Lebanon, Lebanese Atomic Energy Commission

Since its installation in 1999, the 1.7 MV ion beam tandem accelerator at the Lebanese Atomic Energy Commission is in a continuous upgrade process in order to offer the best performance. This is also meant to respond as much as possible to the needs of our scientific collaborators from different disciplines such as archeology, environment and materials science. In this perspective, several data acquisition systems, including instrumentation and software, were added to the main setup. These mainly concerned the PIXE technique, since the detection system evolved from a Si(Li) detector to a SDD one. In addition, a new external micro-beam was installed, comprising 2 SDD detectors and a new data acquisition system. The injector system was also upgraded to accommodate the new micro-beam line, consisting of a dual ion source with a computerized control system. Finally, different acquisition systems, including analogue and digital, were used for different experiments.

Control system for industrial linear electron accelerator

Zbigniew ZIMEK, Poland, Institute of Nuclear Chemistry and Technology

The radiation facility located at the Institute of Nuclear Chemistry and Technology in Warsaw has been designed and built in order to provide higher technical and economical effectiveness, along with better operational characteristics suitable for radiation processing (radiation sterilization). The objectives of the project were an electron energy of 10 MeV, 10-15 kW beam power, a linear electron accelerator equipped with a microwave source based on the modern klystron TH2158 device operated at a frequency 2856 MHz and a standing wave accelerating section.

The implemented accelerator control system is equipped with PLC-based Siemens microprocessors and Simatic S7-300 modules, with a Profibus communication channel and a SCADA tool (Supervisory Control And Data Acquisition) WinCC. The structure of the control system consists of: microprocessor, interface modules, analog and digital input/output modules, functional counter module, extension unit to RS232 interfaces and touch panels. The basic functions of accelerator control system, such as switching all independent units, starting up and down procedures and automatic parameters stabilization are controlled by a microprocessor.

These functions are extended by an applied facility control system for process control which includes:

- Accelerator control system (accelerator equipment and parameter operation, authorized access)
- Safety and interlock control system (personnel safety, safe facility operation, alarm and automatic stop)
- In beam device control system (product handling device, dose adjustment without interruption irradiation process, bar code readers, monitoring and recording process parameters)
- Quality control system (continuous electron beam diagnostic: current, energy, energy spread, dose, position measurements)
- Management and data processing tool (reporting, statistical reports, data tracking, trending, archiving)

The facility control system is responsible for precisely delivering the required dose and data acquisition in sterilization process through active beam process control. The unit is acting as a central historical data recall and is available for product tracking purposes. The control system is an accelerator management tool which should be rapidly accessible and should include features such as remote control, multi-language support, and automatic conditioning.

ATCA/MTCA control and data acquisition platform for accelerator experiments

Jorge ROSA LOPES DE SOUSA, Portugal, Instituto Superior Tecnico

In the last decade, the Instituto Superior Tecnico (IST) has successfully designed and deployed an instrumentation platform for fusion diagnostics and plasma control, currently in operation in various sites such as JET, IPP, IPP-CR, RFX, USP, INPE, and prototyped for ITER. Control and Data Acquisition systems for Gamma-ray/Neutron, Time-of-Flight and Magnetic Proton Recoil Neutron Spectrometers designed for high-count rate, Neutron Camera, Plasma Control at JET/COMPASS/ISTTOK, Microwave Reflectometry, as well as CODAC implementations were the main areas of application.

The platform's high-speed data transport is based on the PICMG ATCA (over PCI Express) hardware standard. The real-time data processing is performed mainly by the FPGA's (for specific fast signal processing algorithms) and the MARTe real-time framework. Local control systems are based on EPICS and operation software is based on MDSPlus. The modular platform is designed for high-availability, supported by scalable redundancy mechanisms at various design levels, independent hardware management, module hot-swap mechanism and a system manager software that monitors the platform modules' health, performing fault detection and supporting fast mitigation. The platform also allows the relocation of sensitive hardware from hazardous radiation locations and supports absolute-time (IEEE-1588, White Rabbit and IRIG) time-stamping, synchronization and real-time event management embedded on the acquisition hardware. The platform was extended to smaller, lower-cost systems with a MicroTCA based design which maintains the required performance characteristics of speed, channel density and availability of ATCA's. This compact, flexible and scalable platform may either integrate a large-experiment system infrastructure, as well as being configured as a lower-cost, self-contained platform for smaller experiments or development and testbench purposes.

Recently, IST started collaborating in accelerator-based experiments, on the specification of the real-time processing infrastructure for DONES-ENS and a spectrometer for the IST/CTN accelerator.

Compact detector for high energy lepton/photon spectrometry

Constantin Mihai CUCIUC, Romania, IFIN-HH

A compact detector is being developed at ELI-NP for measuring both energy and degree of linear polarization of a GeV gamma beam. Using the polarization dependent cross-section of the pair production process, both of these quantities can be estimated on the same sample of photons. The electron-positron pairs' kinematic properties are measured using a combination of pixelated silicon layers and magnetic field, thus enabling the reconstruction of the incoming gamma photon that generated the pair.

This also makes the detector very well suited for performing spectrometry of electrons or muons and a prototype is currently being evaluated at ELI-NP using cosmic muons to tune the triggering and synchronization of the DAQ hardware and software. A custom solution has been developed for readout of the INTPIX4 sensors using SEABAS2 readout boards, both sensors and boards being developed at KEK. The DAQ boards offer readout via TCP/IP over gigabit Ethernet as well as full access to the FPGA that controls the pixelated sensor and to the data stream from the ADCs. This flexibility allows seamless integration with any necessary trigger configuration or detector synchronization.

Data Acquisition Systems for the Multi-Detector Array RoSphere

Lucian STAN, Romania, IFIN-HH

The RoSphere gamma spectroscopy array is placed on the first beamline of the 9MV Tandem accelerator in Magurele, Romania. It has 25 detector positions which can house Compton-shielded HPGe detectors, LaBr₃(Ce) scintillators or liquid-scintillator neutron detectors in various configurations. RoSphere is mainly used in experiments studying nuclear structure using fusion-evaporation and nucleon transfer reactions, especially for the construction of level schemes and excited state lifetime determinations using fast timing, plunger and DSAM techniques.

In order to handle the large number of signals coming from the detectors, a CAMAC-based Data Acquisition system was originally employed, but this was substituted by a more powerful VME-based system, along with many other improvements and the use of a new customised open-source DAQ program. Currently, there are plans to expand the DAQ program and system in several directions, including the use of digitizers in the next couple of years.

Data acquisition system of Ion Beam Analysis Laboratory in Trnava

Jozef DOBROVODSKY, Slovakia, Faculty of Materials Science and Technology in Trnava

The new Ion Beam Laboratory, based on the 6 MV Tandem accelerator, was put into operation at the end of 2015. It was built within the European Structural & Investment Funds (ESIF) project „University Science Park CAMBO” and a significant part of it is devoted to Ion Beam Analysis (IBA). The ion accelerator, ion beam transport and the IBA measuring devices form an interconnected system, supplied by High Voltage Engineering Europa B.V. The IBA includes measuring systems for RBS, channeling, ERDA, PIXE and NRA. The standard analog nuclear electronics is used for signal processing and a multiparameter multichannel analyzer system is used for data acquisition. The design of the new high energy ToF ERDA system is in progress, which will involve combination of high resolution multi-stop ToF system with a multiparameter Data Acquisition system (Fast ComTec model MPA-4T).

An integrated MIDAS and LabView based data acquisition, scanning and stage control system for the nuclear microprobe at iThemba LABS.

Caswell PIETERS, South Africa, iThemba LABS

Due to the obsolescence of the VAX workstations running the XSYS general purpose data acquisition package for PIXE, PIGE, RBS and mapping, the decision was made to replace these and connected components with modern software frameworks and hardware. A system was designed to integrate a multi-channel software frontend and online analyzers based on the MIDAS data acquisition framework developed at PSI/Triumf, along with PCI, PXI and C series National Instruments modules for both computer and hardware joystick stage control, FPGA-generated time critical scanning, beam blanking, ADC gating, total X-ray counting and scan coordinate tracking.

A graphical user interface developed in LabVIEW communicates via calls to an online database that contains all the information needed to run and control an experiment. This is done by remote procedure calls from a Windows library or by a dedicated http server that can be accessed in a web interface, with pages customizable through a JavaScript library. Data files are synced using ownCloud and are immediately available for offline analysis on connected client PC's, as well as for the transfer of GeoPIXE dmm files for real-time image projection using the Dynamic Analysis method.

A Stanford Research Systems low-noise current preamplifier is used along with a Quantum Detectors 1MHz V2F module connected to a scaler for capturing scanning charge maps. List mode files are created with metadata stored in a JSON header, as well as ROOT-defined energy spectra and maps for online and offline viewing. The configuration and integration of these hardware and software components was discussed, along with preliminary results. The Dolosse Project, which aims to modernise the aggregation of disparate data acquisition systems and analysis methods, using existing enterprise-grade, open source platforms was also briefly discussed.

Sub-nanosecond spectroscopy with digital electronics

Peter Michael JONES, South Africa, iThemba LABS

The use of fast-timing detectors, such as LaBr₃(Ce) detectors, is becoming more commonplace in nuclear physics, both standalone and also integrated with other detectors such as HPGe detectors. These detectors require fast (≥ 500 MHz) sampling digitisers and a triggerless data acquisition system, such as implemented at iThemba LABS. Using direct fast-digitisation techniques on the signals (< 50 ns) allows for increased count rates, keeping detector energy resolution provided a decent (≥ 14) bit digitisation is provided.

These data have to be collated and merged with other detectors from other digitisers (100 MHz, 250 MHz) and with natively different timestamps, a common frequency should be considered. Combining other data streams also should have an agreed timebase, but the best common timebase for these and future data at even higher sampling rates should be carefully considered.

Fast scintillators are also used for environmental uses in the field together with position accurate measurements (via GPS / Galileo) which also operate at frequencies > 1 GHz. This could be an ideal way to combine from ground base sampling and to relate data.

Development of a digital data acquisition system for neutron metrology

Chloe SOLE, South Africa, University of Cape Town, in collaboration with the IRSN (France)

Neutron fields are found in a variety of industries, such as high energy accelerators and medical radiation facilities. These fields vary widely with respect to energy, type of radiation and fluence. Neutron energy spectra are typically measured using Bonner sphere detector systems, which do not have a good-enough energy resolution. Systems based on scintillator detectors provide better energy resolution and a number of other advantages. A disadvantage of using scintillator detectors is their sensitivity to all types of radiation, requiring complex analysis of pulses to select for a particular type of radiation. The advent of digital pulse processing electronics has made it possible to move from being heavily reliant on analogue electronics coupled to a Bonner sphere detector system, to scintillator based systems coupled to compact digital electronics as a standard.

Most neutron metrology groups around the world are thus developing systems of digital pulse processing to replace their aging analogue systems, which are suitable for use in a wide range of contexts and a wide range of detector types. Digital systems provide a number of advantages over their analogue counterparts, such as the ability to capture waveforms at high rate, allowing the replay of an experiment with different analysis parameters. This presents new optimization capabilities for analysis parameters. This is not easily executed in analogue pulse processing. Furthermore, digital acquisition systems are much more portable and flexible for a large range of applications. One issue with digital data acquisition systems is that the quality of information is highly dependent on the sampling rate and ADC bit size. A limited input voltage range is another tight constraint enforced by digital data acquisition.

Progress on the benchmarking and intercomparison between a new CAEN based digital data acquisition system and the standard analogue NIM electronics used for fast neutron spectroscopy and metrology was presented. A comparison between the two acquisition systems was shown with some preliminary results from data taken at AMANDE.

Perspectives and first applications of the Tango control system to electrostatic accelerators

Victor JOCO, Spain, CMAM Madrid

The use of a distributed control system built with the open source Tango toolkit has been considered for a small electrostatic accelerator. This has allowed the integration of the factory control system into a distributed network and assured flexible and easy extensions. The change is fulfilling the needs imposed by machine upgrades and the addition or modifications of beamlines which are regularly improved to keep the infrastructure competitive and productive. The transition from a stand-alone to a distributed system was discussed, first applications were detailed and future advancements were proposed.

Particle Accelerator Facilities and Data Acquisition Systems in Thailand

Penphitcha AMONPATTARAKIT, *Thailand, Synchrotron Light Research Institute* and

Thawatchart CHULAPAKORN, *Thailand, Thailand Institute of Nuclear Technology*

Research based on the use of particle accelerator facilities in Thailand has been conducted for several decades. At the beginning, the facilities were owned by the Chiang Mai university, where the ion physics has been limitedly studied. A 1.7 MV Tandem accelerator, donated by Charlmers University of Technology in 2000, is the only MeV-electrostatic accelerator in Thailand. The accelerator has been used for Ion Beam Analysis (IBA) techniques including Rutherford Backscattering Spectrometry (RBS), Particle-Induced X-ray Emission (PIXE) and IonoLuminescence (IL). The data acquisition systems connected to the detectors are analogue. The current status of this facility is at the stage of moving toward microprobe analysis, using capillary glass for focusing ion beams. A new generation of data acquisition systems is planned which needs to be compact and, possibly, integrated with digital and automated systems. In the past 12 years, national laboratories were established to run national and also regional large research facilities in Thailand.

The Thailand Institute of Nuclear Technology (TINT) plans to commission a 30/15 p/d MeV cyclotron for radioisotope production and ion beam analysis. The IBA system at this facility will be used for in-air PIXE, Particle Induced Gamma-ray Emission (PIGE), as well as Thin-Layer Activation analysis (TLA) for industries and basic research. The data acquisition systems are commercial and digital, and a synchronization of different systems is required to send the data to a safety area located outside the experimental hall.

The Synchrotron Light Research Institute (SLRI) has a 1.2 GeV electron synchrotron facility, located at Nakhon Ratchasima. The facility consists of 4 insertion devices with 10 beamlines and 12 end-stations. The maximum beam current is 150 mA, which gradually decreases during the 12-hour operation time each day. There are about 400 users utilizing the facility each year.

There are several synchrotron-based techniques that are in use, including X-ray scattering, X-ray absorption spectroscopy, X-ray lithography, Infrared micro-spectroscopy, Macromolecular crystallography and X-ray Tomography. For instance, the data acquisition system at Beamline 8 is used for X-ray absorption spectroscopy (XAS).

In order to detect X-rays, a 7-element Si Drift Detector (SDD) and a 13-element Hyper Pure Germanium (HPGe) detector are located at positions perpendicular to the incident X-rays. A new 3 GeV electron synchrotron facility is also planned to be commissioned in 2026, comprising 7 beamlines.

Data Acquisition Systems of the IAP NASU Accelerator-Based Analytical Complex

Serhii KRYKLIA, Ukraine, Institute of Applied Physics, National Academy of Sciences of Ukraine

An analytical accelerating facility was constructed at IAP NAS in Ukraine on the basis of a compact electrostatic accelerator of a horizontal type. The maximum accelerating potential is 2 MV. The facility has five analytical end-stations: a scanning ion microprobe end-station with spatial resolution of less than 2 μm , a high-resolution Rutherford backscattering spectrometry end-station with a magnetic spectrometer ($\Delta E/E < 1.5 \times 10^{-3}$), an end station for elastic recoil detection analysis equipped with an electrostatic spectrometer ($\Delta E/E < 1.5 \times 10^{-3}$), an end-station for particle induced gamma-ray spectroscopy and an ion induced luminescence end-station. A quasi-monochromatic X-ray source end-station is under intensive development. This facility will be employed for testing elements of X-ray optics and components of detection systems for X-ray phase contrast imaging.

All end-stations are supplied with separate data acquisition systems. The most common setup is represented by various detectors, preamplifiers, amplifiers, analog ADCs and control systems. The high-resolution Rutherford backscattering spectrometry end-station is equipped with a homemade control and data collection system for the magnetic spectrometer. For the PIGE analysis data acquisition, the fast SSD detector is connected to a Digital Pulse Processor. The Positron Annihilation Lifetime Spectroscopy setup requires high-speed data acquisition electronics. In our case, this is a DRS4 Evaluation board developed by the Paul Scherrer Institute (PSI). The software part of the data acquisition is represented by a combination of commercial products, open source variants and homemade codes.