INTRODUCTION TO CARBS IBA ACCELERATOR SYSTEM

National Electrostatics Corp.

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National Electrostatics Corp.
Over 50 Years of Accelerator Experience

National Electrostatics Corp. (NEC) provides industry-leading electrostatic ion beam accelerator systems and related components designed to expand the research goals of scientific and technical communities around the world. We pride ourselves on supporting our customers through the lifetime of our products.

Beginning in the 1930s, Professor Ray Herb of the University of Wisconsin adapted the electrostatic generator concepts to work in pressure vessels. Over the next 30 years at the university, he developed the beam column configurations used on all modern electrostatic accelerators. He invented many pivotal components, such as the generating voltmeter, the corona probe stabilization system, charging chains, the electrostatic analyzer, and titanium getter pumps, and pioneered ceramic-to-metal bonding technology.

The results of his work led to the formation of NEC and its rapid rise to its leading role in manufacturing electrostatic accelerators. Prof. Herb, along with two colleagues, incorporated NEC in 1965 in Middleton, Wisconsin, USA.

In its first 20 years, NEC successfully built and installed over 40 accelerator systems, including the largest tandem accelerators in the world: the 25 MV tandem at Oak Ridge National Laboratory (ORNL) in the USA; the 20 MV tandems in Japan and Argentina; the 14 MV tandems in Australia and Israel; and the 12 MV tandem in Japan. Some of these large systems pioneered the use of accelerator computer control systems.

During the same time period, NEC provided the accelerator for the world's first MeV ion-beam microprobe, the first production MeV implantation system for the semiconductor industry, as well as many other Pelletron® accelerator systems.

The 7,000 square meter NEC complex is a complete manufacturing facility that includes computer controlled and manual machine shops, electronic assembly, component assembly, and extensive ion beam system assembly and test areas.

To date, there are over 240 NEC accelerator systems worldwide and over 200 ion sources sold for use on other equipment. NEC products are robust and designed for both research and industrial applications.

CARBS (Compact Automated Rutherford Backscattering Spectrometry)Accelerator System

The CARBS accelerator system is a completely automated instrument for Ion Beam Analysis (IBA), specifically Rutherford Backscattering Spectrometry (RBS) and high depth resolution RBS (HR-RBS).

The CARBS system is designed to be easy to operate with a compact footprint, automatic operation and data collection, and a positive ion source that can operate for thousands of hours with no maintenance. The CARBS system can also be expanded to 1.0 MV or 2.5 MV for NRA or PIXE capability.

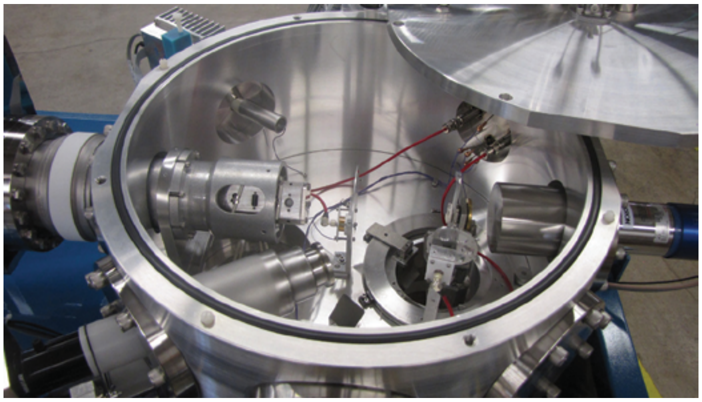
CARBS System IBA Techniques

The CARBS system is designed for RBS and HR-RBS (optional). The versatile design allows for additional IBA techniques to be added during design or added in the future.

Ion Beam Analysis refers to a variety of accelerator techniques that mainly focus on interactions between MeV light ions (H, He) and materials. All IBA techniques are extremely sensitive and allow the detection of elements in the first micrometers of a material, or deeper. Typical IBA techniques require beam energies ranging from 0.5 MeV to 6 MeV.

Common IBA techniques include:

- RBS (Rutherford Backscattering Spectrometry): measures heavy elements in a light matrix
- ERD (Elastic Recoil Detection): measures light elements in a heavy matrix
- PIXE (Particle-Induced X-ray Emission): provides trace and minor elemental composition
- NRA (Nuclear Reaction Analysis): measures specific isotopes
- Channeling: measures defects and dopant interstitial or substitutional locations in major and minor axes of crystal structures



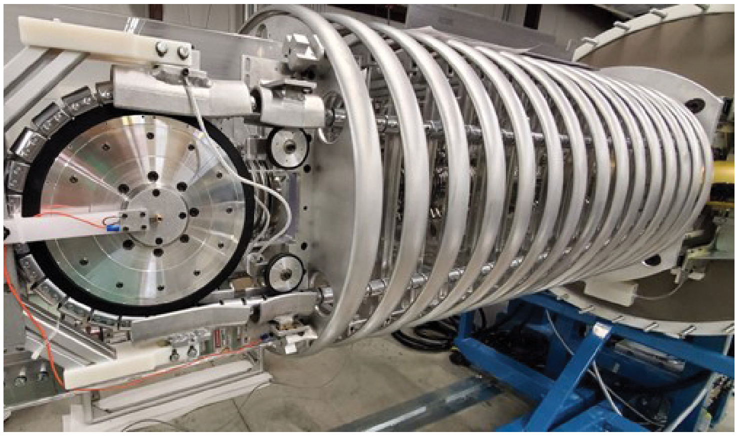
CARBS System Features

- Monolayer depth resolution: down to 5 Angstroms (HR-RBS)
- Compact layout: as small as 4 m x 3.5 m
- Automated operation and analysis: System can run through the sample list and shut down
- Long source life with minimal maintenance: Over 1,000 hours between service
- Excellent beam stability: +/-50 eV

IBA Applications

- Radiation damage
- Nuclear physics
- Biology
- Material science
- Environmental science
- Art science
- Archaeology
- Geophysics
- Medicine
- Forensics science
- Aerospace science
- Food science
- Anthropology
- And many more...

How the CARBS Accelerator System Works



The CARBS system was designed specifically to provide the same or better results as a traditional tandem IBA system, in a more compact setup and with more automation and user-friendly features.

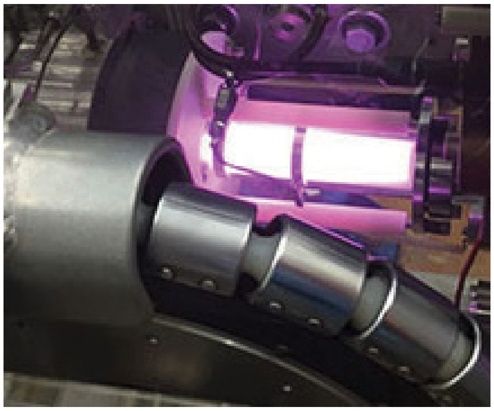
Single-Ended Accelerator

The key components of an NEC accelerator system are contained in the pressure vessel, often referred to as the Pelletron® or tank. The CARBS is a single-ended Pelletron: it has a high-voltage terminal at one end of the acceleration tube and a positive ion source inside the terminal.

The exit of the Pelletron is at ground potential, where the ion beam emerges with an energy equivalent to the terminal voltage plus source potential.

By using a single-ended accelerator rather than a traditional tandem accelerator, the beam stability is greatly improved from several hundred eV down to 50 eV. The footprint of the Pelletron tank is approximately half of that of a tandem.

Positive Ion Source

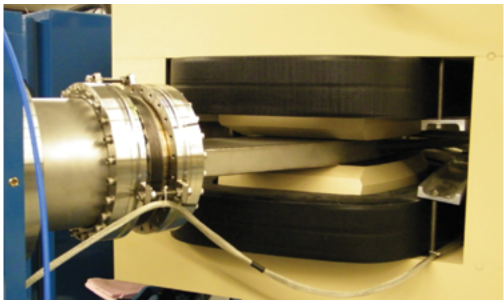


An NEC positive ion source is installed in the terminal of the CARBS accelerator. This source is used primarily to produce hydrogen and helium ion beams. However, it also produces modest currents of oxygen, chlorine, and other positive ions from gaseous elements.

Using a positive ion source allows for less source maintenance due to the lack of a rubidium charge-exchange cell. The interval for replacing canals and insulators can be up to several thousand hours of run time at moderate currents.

Produces:

- Hydrogen
- Helium
- Oxygen
- Chlorine
- and more ...



90-Degree Magnet

Post acceleration, the beam passes through a 90-degree, double-focusing magnet for proper mass analysis. The beam transmission is optimized for focusing into the IBA chamber.

IBA Endstation

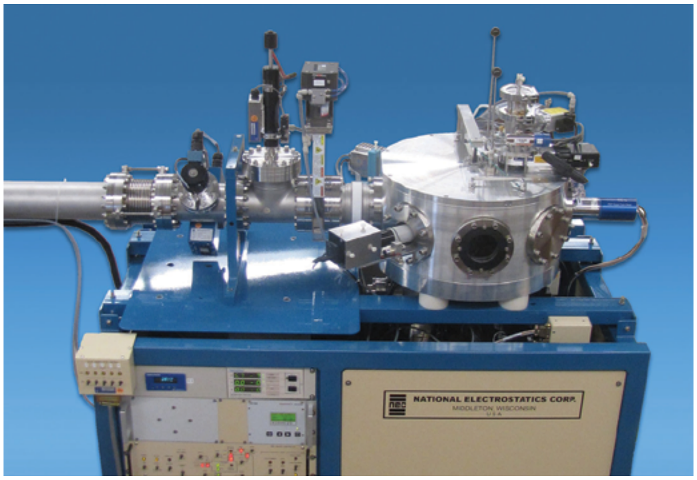
The beam then enters NEC's standard IBA endstation for analysis. The IBA endstation includes a Silicon Surface Barrier (SSB) detector for RBS analysis. Additional detectors for other techniques can be added.

The scattering chamber can accommodate up to 16 samples, 1cm x 1cm, side by side. It includes a vacuum load lock, view port, target alignment laser, and video camera. It is electrically isolated and can be used as a Faraday cup for precise beam current measurements.

A 5-axis sample manipulator provides X and Z motions of +/- 12.5 mm and Y motion of +/- 50 mm with resolution of 0.001 mm. Theta axis rotations of +/- 160° and Phi rotation is continuous, both having 0.01° resolution. The samples are positioned by the control computer, which controls all five motors simultaneously.

A digital current integrator is provided to measure total ion beam current and provide gate signals for all detector measurements by monitoring total ion current on the target.

The IBA endstation computer manages the sample positioning and data acquisition. The control system includes software for both qualitative and quantitative analysis including RC43 Analytical Data Collection software and RUMP/SIMNRA respectively. The IBA control system will communicate with the accelerator control system for enhanced automation.



RC43 Endstation Features

- Holds up to 16 samples side by side
- 5-axis target manipulator
- Can include detectors for RBS, Channeling, ERD, PIXE, PIGE, NRA, and IBIL
- Analysis computer incorporates software that:
  - allows for 6 spectra to be gathered simultaneously
  - allows for up to 10 spectra to be plotted and overlaid with color and line styles that are automatically changed

HR-RBS Detector System

The HR-RBS detector can be added to the CARBS system to allow for high-resolution detection of the scattered beam. This detector provides monolayer depth profile sensitivity (~5 angstrom).

HR-RBS Features

- Energy Resolution: 1 keV
- Accurate positioning for small-angle grazing measurements
- Designed for compatibility with RC43 endstation; however, can be configured to fit with other experimental chambers
- Equipped with all necessary hardware and software for automated RBS data collection and analysis
- Advantages over traditional IBA include: depth sensitivity, H profiling, crystal quality dopant location, and more

Analysis Computer

The IBA endstation computer manages the sample positioning data acquisition with qualitative and quantitative analysis. The IBA control system will communicate with the accelerator control system for enhanced automation, including system start up, sample queue data collection, channel axis location and aligned data collection, and shut down when sample list is completed. Each of the previously mentioned IBA techniques are measured simultaneously and displayed on screen.

Options

There are three versions of the CARBS, based on the terminal voltage of the Pelletron. We offer terminal voltages of 0.5 MV, 1.0 MV, and 2.5 MV. The optimal beam energy is related to the techniques of interest.

The Optimal Beam Energy for Your Technique	
0.5 & 1 MV	**2.5 MV**
Primarily for high-resolution RBS and forward-scattering ERD for thin samples ~1000 Angstroms	Allows standard PIXE and ERD as well as some nuclear reactions for depth profiling of thicker samples of ~2 microns. PIXE is primarily done with protons around 2.5 MeV.

System Performance and Specifications

Beam Current	He+ > 100 nA
Beam Energy Stability	< 50 eV RMS
RBS Demonstration	Known samples, provided by customer, will be analyzed by RBS/HR-RBS to demonstrate proper function of the system. The sample should have a film thickness between 10Å to 50Å to show angstrom-level depth resolution. Many samples can be analyzed in 5-10 minutes.
Elemental Composition vs. Depth	Depth profile for elements to monolayer resolution (1-2 monolayers depending on the element)
Elemental Sensitivity	Ranges from 0.01% for heavy elements to a few percent for light elements

Examples of HR-RBS Data

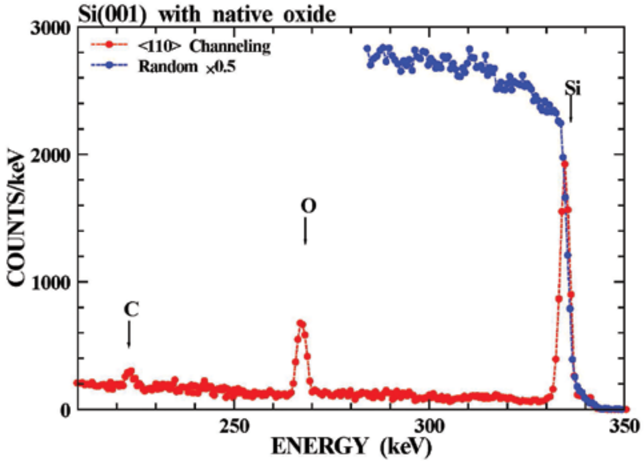


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Image 1

- High-Resolution RBS plot of Silicon with native SiO2 layer and Carbon surface contamination. Channeling data, in red, reduces Si background by a factor of 20 and improves sensitivity to light elements.

he red dots show the silicon-background-subtracted channeling spectrum.

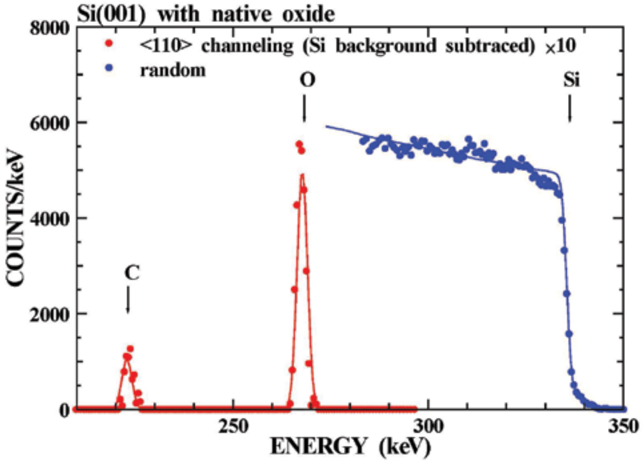

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Image 2

- HRBS data with Si background subtracted to highlight monolayer light element sensitivity.

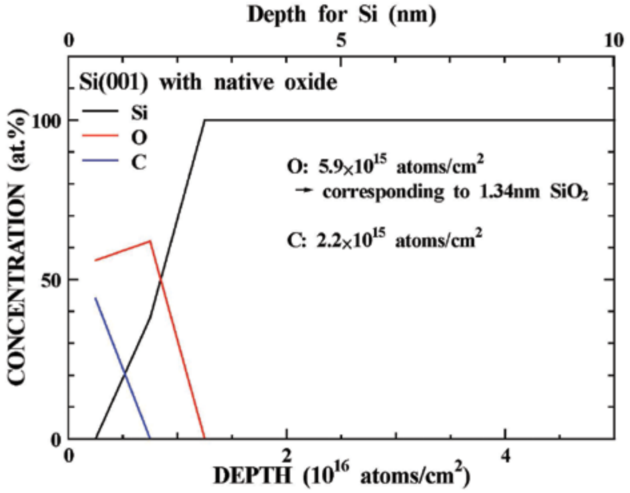

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Image 3

- Depth profile for Silicon, Oxygen, and Carbon with areal densities for O and C for surface 10 nm. Shows depth resolution of a few angstroms.

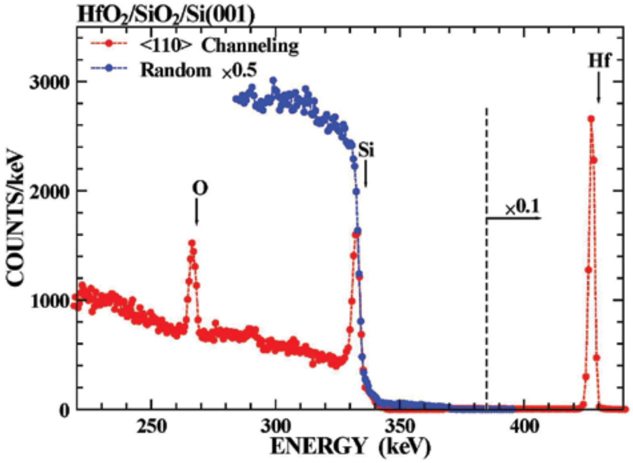

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Image 4

- High-Resolution RBS plot of Hafnium Oxide/Silicon Oxide/Silicon substrate. Channeling data in red reduces Si background by a factor of 10 to improve sensitivity to light elements. HfO2 film reduces Si substrate reduction.

e blue dots show the silicon-background-subtracted channeling spectrum.

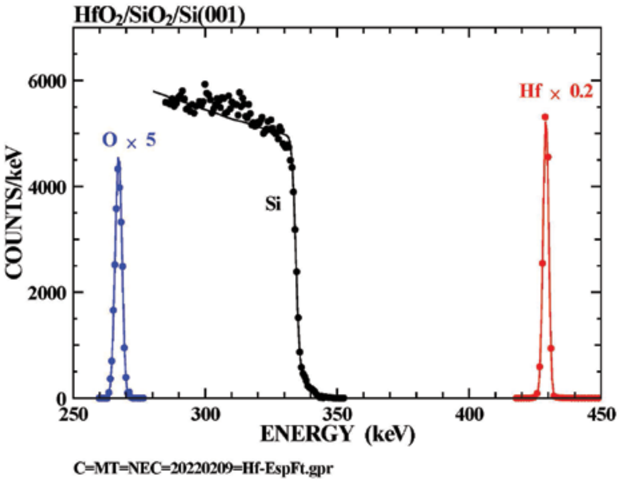


Image 5

- Silicon background subtracted to enhance light elements.

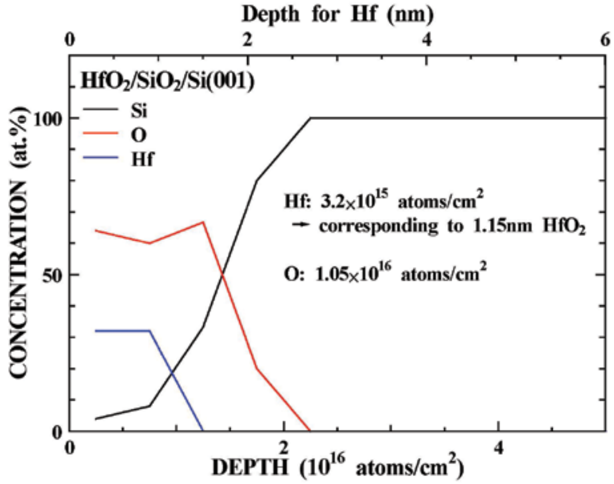


Image 6

- Atomic concentration profile vs depth for Hafnium, Oxygen, and Silicon for surface region with calculated areal densities.

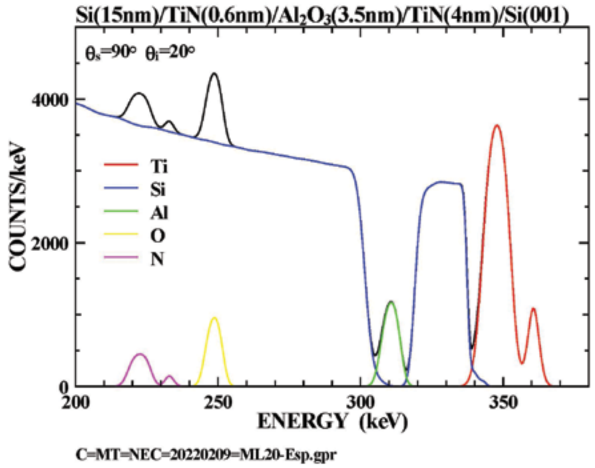


Image 7

- HRBS simulated spectrum, blue, of multilayer thin film with individual element components, in other colors, with good elemental separation.

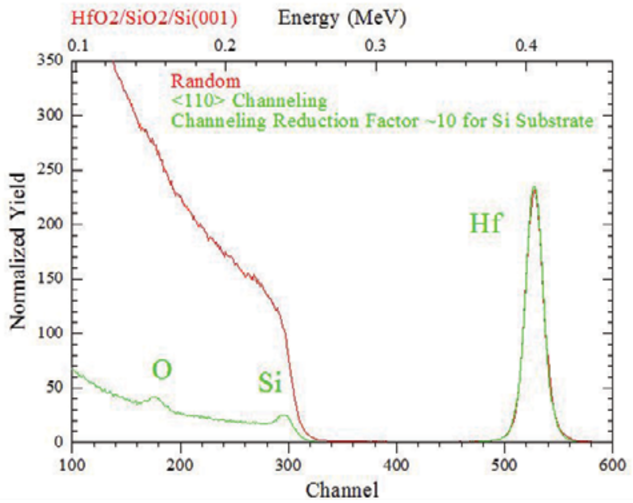


Image 8

- RBS spectra used to generate areal concentrations for HfO2/SiO2 thin films. With this information HRBS will generate monolayer depth resolution concentration profiles.

Control System

NEC pioneered accelerator computer control systems, setting the standard for future generations of accelerators. The NEC computer control system's core is the in-house designed control software, AccelNET. With an AccelNET control system, an operator can control individual devices or save setups for semiautomatic operation. Thorough software and hardware interlocking is integrated into the control system. Since 2007, controls and readouts interface with the control console via an in-house interface system, ACT.

NEC AccelNET Control System

In the late 1970s NEC built a series of large electrostatic tandem accelerators with the first computer control systems. These included the largest in the world, the 25 MV system at Oak Ridge National Lab (ORNL), and 20 MV systems at the Japan Atomic Energy Agency (JAEA) and the Argentina National Atomic Energy Commission (CNEA).

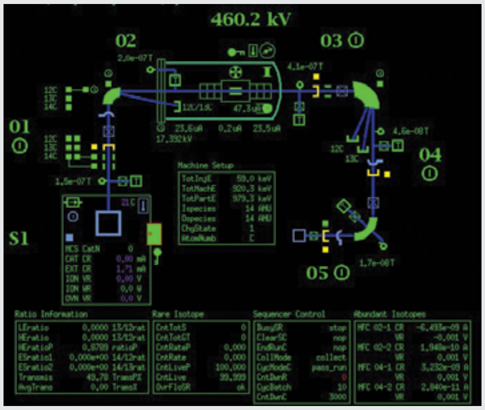
Since then, more than 140 accelerators have been installed with a computer system configured with NEC accelerator control software, AccelNET. AccelNET operates under the Linux operating system and is network-based and scalable. Within this stable and secure environment, the operator can control the accelerator, ion sources, beamlines, target chambers, and data collection in a variety of ways, from completely manual control of individual devices to semiautomatic operation via presaved routines.

In the automatic mode, operators can load existing setups and start ion sources and the accelerator with a few commands, and quickly restore operating conditions from previous experiments. For high-precision techniques, such as Accelerator Mass Spectrometry (AMS), automatic optimization of optical parameters assist the operator to reach perfect beam tuning.

In the manual mode, regardless of the size and complexity of a system, the operator can access and control individual devices from a diagrammatic display window or from detailed parameter lists. Parameters can be changed using convenient assignable knobs, which are helpful when fine-tuning optical devices.

Remote operation of the control system is possible via local networks or secure Internet connections. In addition, AccelNET can control, or be controlled, by other programs such as Labview and EPICS.

The control system allows for comprehensive interlocking and reporting in both hardware and software, and fail-safe shutdown features allow for unattended sample sequence control and data collection and logging. This allows for safe unattended operation without compromising data.



Machine Setup

TotInjE	59.0	keV
TotMachE	920.3	keV
TotPartE	979.3	keV
Ispecies	14	AMU
Ospecies	14	AMU
ChgState	1	
AtomNumb	C	

MCS CatN	0	
CAT CR	0.00	mA
EXT CR	1.71	mA
ION VR	0.00	V
ION WR	0.0	W
OVN VR	0.0	V

Ratio Information

LEratio	0.0000	13/12rat
HEratio	0.0000	13/12rat
HEratioP	0.8789	ratioP
ESratio1	0.000e+00	14/12rat
ESratio2	0.000e+00	14/13rat
Transmis	49.78	TransPX
AvgTrans	0.00	TransX

Rare Isotope

CntTotS	0
CntTotGT	0
CntRateP	0.000
CntRate	0.000
CntLiveP	100.000
CntLive	99.999
OvrFloSR	ok

Sequencer Control

BusySR	stop
ClearSC	nop
EndRunC	nop
CollMode	collect
CycModeC	pass_run
CntDwnR	0
CycBatch	10
CntDwnC	3000

Abundant Isotopes

MFC 02-1	CR	-6.493e-09	A
	VR	-0.001	V
MFC 02-2	CR	1.948e-10	A
	VR	0.001	V
MFC 04-1	CR	3.232e-09	A
	VR	0.001	V
MFC 04-2	CR	2.840e-11	A
	VR	0.001	V

AccelNET is entirely written and maintained by a team of in-house experts; it does not depend on consultants or subcontractors. Therefore, support is readily available, and with permission, NEC can remotely diagnose and correct problems, perform software upgrades and database changes, and even assist in accelerator operation and troubleshooting.

For AMS, special programs integrated into AccelNET allow completely automatic sample control and data collection. One such program is DMAN. Based on a list of sample positions and names, DMAN will automatically advance samples and run them for preset times in a variety of user-chosen modes. It will display ratios, statistical information, by run, by sample, and by group in real time. In addition, DMAN gathers and stores all the AMS data in text files, including all stable isotope current readings, all rare isotope detector signals, and critical spectrometer parameters chosen by the operator. By securely logging the complete AMS data, DMAN ensures that valuable samples will be measured correctly, and the data will be available for re-analysis at any time.

In combination with NEC Beam Profile Monitors (BPM) and display units, AccelNET allows convenient selection, display, and gain control of as many BPMs as needed, regardless of the complexity of the accelerator system. The same display system can display AMS signals if needed for tuning, or time varying voltages and currents in implantation raster scanning systems.

NEC ACT Computer Interface System

Early NEC control systems depended on international standard CAMAC analog and digital I/O modules, combined with NEC interfaces that sorted the signals from different modules into convenient and reliable individual connectors to each component, power supply, or device. In the mid-2000s NEC designed its own interfacing system. This modular interfacing system, ACT, improves upon previous conventional systems with 16-bit precision, and unique features to allow the operator to measure signal levels for every analog channel at the front panel, to see relative levels for all channels by the intensity of individual LED lamps, and to see at a glance that communication to the control computer is active.

The ACT system employs a “watchdog” timer system that will safely shut down power supplies and the accelerator and close Faraday cups and beamline valves if communication to the control computer is lost.

ACT has demonstrated outstanding reliability and ruggedness, and the NEC in-house control of the design and production guarantees that the system will be available and supported over the long lifetimes of NEC accelerators.

> *NEC has delivered over 125 ACT systems, with nearly 800 modules and well over 13,000 analog and digital channels.*

AccelNET Features

- Magnet closed loop operation allows full recovery of stored settings without the necessity of operator tuning
- Flat-topping routine can act on any given parameter, display the openness of the beam transport, and set the parameter to the best value
- 24-channel analog strip chart recorder allows the operator to monitor complex events at a glance
- Channels are scalable and can be assigned quickly
- Assignment groups are savable
- Time base is adjustable
- Beam currents and other tunable parameters are viewable
- Histogram display capabilities are used for AMS detector signals or for pulsing systems to display pulse shape

ACT Features

- Reliable operation
- Rugged to survive accelerator environment
- Convenient individual connectors for each device to be controlled
- Simple command structure
- Precise (16-bit)
- Measurable signal levels for every analog channel at the front panel
- Viewable intensity of individual LED lamps to observe relative levels for all channels
- Viewable indication that communication to the control computer is active
- In-house control of availability & support
- Safe shutdown via watchdog timer

Support and Training

NEC prides itself on its timely and proper responses to inquiries by experienced and well-informed employees. NEC can be contacted directly via phone, email, or the NEC website (www.pelletron.com). Responses to inquiries are typically sent within 1-2 business days.

Commercial Support

The Commercial Support team is available to provide information regarding offered products and can help direct you to the specific product that will meet your needs – whether it be a complete accelerator system, an ion beam component, or a replacement part. They can then follow up with quotations and order processing. The Commercial Support team is knowledgeable on NEC's vast product lines and will be able to provide you information in a timely manner.

Technical Support

Should you need technical support with a system or component, the Technical Support team can provide troubleshooting advice and recommend solutions. You are able to discuss issues directly with engineers familiar with your system via phone, email, or video conference.

In addition, if NEC is given Internet access through your firewall, NEC engineers/technicians can remotely connect to the control system to aid in troubleshooting or maintenance and offer software updates.

All of the above support is provided at no additional charge. NEC offers support for the lifetime of the system, even if the system is relocated to another site. NEC ensures that spare parts will be available for the system as long as possible. In the event that parts become obsolete, suitable replacements will be provided. NEC is able to offer this support by designing and manufacturing many components in-house to limit our reliance on other manufacturers. NEC continues to support the Pelletrons that were installed in the 1970s and 1980s.

If a particular component or electronic unit is faulty, the user may return the item for repair. Repairing a unit is typically more cost effective than replacing a complete unit. The turnaround time for repaired items depends on the type of item and the extent of the repair. Typically, repaired items can be returned within one to two weeks from receipt of the unit; turnaround times as little as one to two days are possible. NEC will make every effort to repair items as quickly as possible to limit system downtime.

If problems cannot be solved remotely or by returning a unit for repair, NEC also offers on-site field service visits by experienced NEC engineers/technicians to provide assistance.

Training

New users and technicians of a system are invited to visit NEC during the assembly and test phase of a new system. They are also encouraged to be involved in the installation process on-site. This allows users to learn about individual components and common troubleshooting techniques. During installation, NEC technicians train users on how to maintain and run the system. NEC also offers on-site training for new staff.

Field Service

NEC engineers/technicians are available to visit a customer's site to perform regular maintenance to a system or assist with troubleshooting a problem that was not able to be resolved remotely. These visits can be scheduled individually or as part of a field service plan.

Standard Field Service Visit

Though the Technical Support staff can typically determine the source of a problem remotely and provide instructions on how to fix it or recommend parts to be sent back to NEC for repair, occasionally the best way to find and fix a problem is to have experienced NEC personnel personally inspect the system. NEC offers field service visits for such situations. Depending on the issue, these visits are typically three to five days, and the experienced NEC engineers/technicians are routinely able to diagnose the problem during the visit. NEC personnel are often available within two to three weeks from visit request, possibly sooner in an emergency.

Regularly scheduled maintenance on the source and Pelletron can be performed by the user. However, some users prefer maintenance to be performed by NEC personnel. Field service visits for maintenance can also be scheduled.

Annual Field Service Plan

NEC understands that it is difficult to budget for unforeseen field service visits as described above. It is also understandable that field service visits may be needed as soon as possible, yet purchase orders may take a long time to process. To solve these problems, NEC offers annual field service plans. An annual field service plan covers one planned maintenance visit and up to two urgent visits within a twelve month period.

The scope of the planned visit is to provide a general preventative maintenance overview of the ion source(s) and the Pelletron accelerator. Complete inspection of the ion source(s), the Pelletron (or high-voltage deck), and the beamlines is provided. Standard system maintenance, such as cleaning the source(s) and replacing consumables, is performed. Additional customer training, recommended system upgrades, and further repairs can be discussed as time allows.

In the event that the ion source(s) or accelerator system are unstable and cannot be diagnosed by NEC personnel via remote support, an urgent field service visit can be scheduled. These visits can typically be performed within one week from visit request, depending on system location and NEC personnel availability. Requests for urgent visits through this service plan have priority over other field service requests.

Included with the field service plan is a 10% discount on consumable parts needed for the maintenance or repair of the ion source(s) and accelerator.

Service plans are tailored to each system and can be adjusted to meet specific user requirements. Service plans can be reviewed, revised, and renewed annually.

NEC Representatives

To help facilitate sales and support outside the U.S., NEC has relationships with external representatives knowledgeable of NEC's products. NEC has worked closely with divisions of Hakuto for more than 40 years, with representatives in Japan, China, and Taiwan. They are experts in installing and maintaining our systems and components. There has been a growing need for contract support in India, and Jesco Projects has provided NEC with excellent support in this area.

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