Nuclear electronics as a pioneer in the development of instrumentation in the 20th century

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Abstract

Nuclear electronics played a decisive role in the development of scientific instrumentation in the 20th century. To prove this statement, the history of instrumentation is discussed starting with the laboratory equipment in the pre-electronics era (1900). Important milestones in the evolution of instrumentation were the use of vacuum tubes (1920), the breakthrough in electronics during the Second World War (Manhattan Project, Los Alamos, 1943-1945), the advent of computers, transistors and the digitalisation based on integrated circuits.

Introduction: Science in the 20th century

In fact two periods can be distinguished in this century:
-1895-1952 Physics period**:** discovery of X-rays, radioactivity, nuclear physics, quantum mechanics, theory of relativity, solid state physics… Nuclear electronics is the driving force in the evolution of instrumentation in research laboratories.
-1953-2000 Biology period: starts with the discovery of the DNA-structure in 1953. Modern biotechnology uses techniques and instruments mainly developed in physics research.
In the second part of the century the development in electronic instrumentation is stimulated by the availability of integrated circuits and the rise of digitalisation. New spearheads are space research, navigation (GPS), telecom, biotechnology and medical imaging (CT-scanners, magnetic resonance imaging).

Laboratory equipment in the pre-electronics era (1900)

The famous Pierre and Marie Curie set-up for the measurement of ionisation caused by radiation from radioactive decay is a good example of an advanced electric measuring system around 1900.

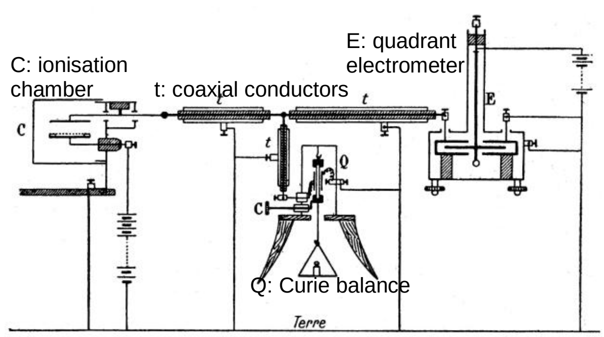
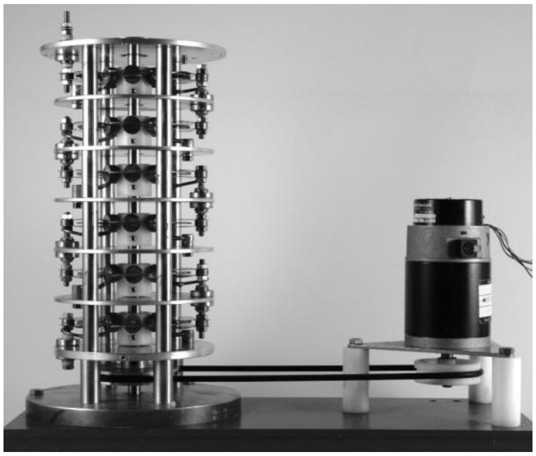


Figure 1. Photograph and schematic view of the Curie set-up with compensation of the ionisation current by the signal from the piëzo-electric Curie balance Q (© Musée Curie, Paris)

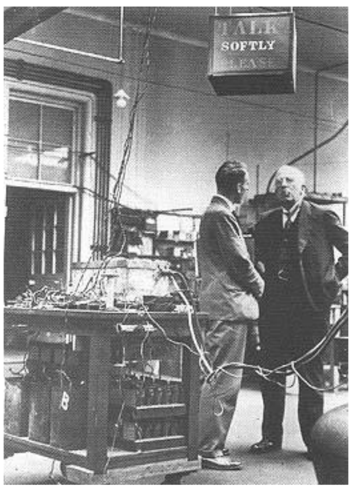
The compensation principle provides high sensitivity; coaxial conductors are used against leakage currents and other interferences.



The “Maschinchen” of Einstein [1] - an electro-mechanical pre-amplifier for small charges in the electron charge range - is another example of the ingenious attempts to make sensitive instruments in pre-electronics era around 1910.
It was not really a success. In literature no scientific articles are found where measurements are described carried out with the Maschinchen.

Figure 2. Photograph of a replica built by the Museum for the History of Sciences at Ghent University [2]

Early electronics 1920-1940



Electronics really started when vacuum tubes (triode in 1907 - Lee De Forest (1873-1961), tetrode in 1916, pentode in 1926) became available as active components for electronic apparatus. Vacuum tube amplifiers were widely used in atomic and nuclear physics research to measure small signals from various detectors. Early instrumentation badly suffers from instability, temperature drift, microphonics and limited vacuum tube life time.
The famous Cavendish Laboratory at Cambridge University (U.K.) with director Ernest Lord Rutherford (1871-1937) provides a good example of early electronic instrumentation.

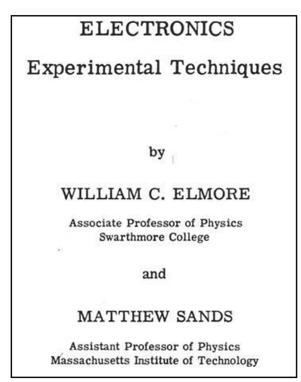
Figure 3. Photograph of E. Rutherford (director at Cavendish Laboratory from 1919 till his death in 1937) with the “TALK **SOFTLY**” panel warning against interferences by sound vibrations (microphony)

The Great Leap Forward: the Manhattan Project - Los Alamos, 1943-1945

The aim of this huge project (1943-1945) was the development of the nuclear fission bomb; it was headed by General Leslie R. Groves (1896-1970) and scientific director Dr. J. Robert Oppenheimer (1904-1967).
Gen. L. Groves describes the Manhattan Project as “a generation of scientific development compressed into three years”; this is surely the case for the advancement in electronics and instrumentation.
The book “Electronics” by W.C. Elmore and M. Sands (1949) contains an overview of the (unclassified) electronic developments at Los Alamos during World War 2 [3].

Figure 4. Gen. L.R. Groves and Dr. J. R. Oppenheimer

The title of the book, simply “Electronics”, is revealing: it contains the state of the art of electronics applicable in all fields of research.


ELECTRONICS
Experimental Techniques

by

WILLIAM C. ELMORE
Associate Professor of Physics
Swarthmore College

and

MATTHEW SANDS
Assistant Professor of Physics
Massachusetts Institute of Technology

Figure 5. Title page of “Electronics” edited by McGRAW-HILL Book Co. (1949)

Some topics from the table of contents in “Electronics”:

Circuit components and construction practice, circuit elements (theory and practice), networks, noise theory, delay lines, amplifiers, feedback loops, oscillators, trigger circuits, multi- and univibrators, flip-flops, clamping circuits, gates, coincidence circuits, voltage amplifiers, pulse-shaping amplifiers, integrators, electronic counters, discriminators, scale-of-ten, integral and differential discriminators, count rate meters, time discriminators, oscillographs, generators, sweep circuits, power supplies and control circuits.

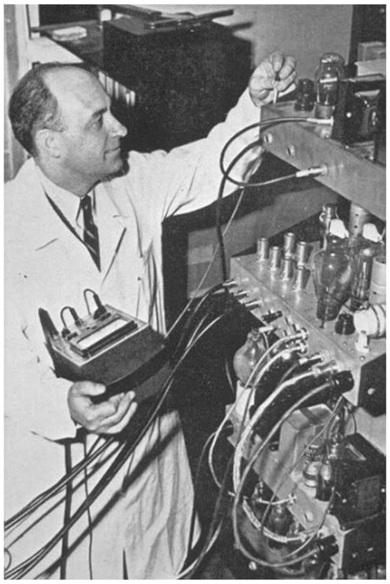


Figure 6. Enrico Fermi (1901-1954) checking the electronics used for the first nuclear bomb test on July 16 1945 at Trinity test site (New Mexico). The Nobel Price 1938 was awarded to Enrico Fermi for his research in nuclear physics

Note the standardisation in the instrumentation in fig. 6:
- 19” rack mounting
- use of “miniature” tubes
- coaxial cables and connectors

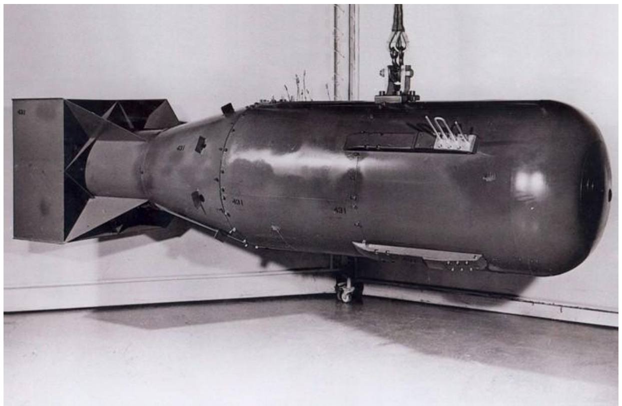
Compare the picture in figure 6 with the situation 20 years earlier in figure 3.

Spin-off the Manhattan Project: isotope separation on industrial scale for nuclear weapons

The scientific results of the Manhattan Project were immediately used for the production of a nuclear weapon. The Hiroshima-bomb was a uranium-235 fission type; the highly enriched U-235 isotope was produced in Oak Ridge in an industrial mass-separation factory, the “Y-12 plant”, using hundreds “Calutrons” electromagnetic mass spectrometers.

Figure 7. Control room of the Calutron mass-spectrometers at Oak Ridge. In the “Y-12 plant” at Oak Ridge, Tennessee, uranium isotopes U-238 and U-235 were separated on industrial scale to produce the first U-bomb.

Figure 8. First U-bomb called “little boy” was used on August 6, 1945 against the city of Hiroshima, Japan



Nuclear electronics as a pioneer in laboratory instrumentation (1945-1970)

In the first years after WW2, lot of instrumentation in research was home-made. Commercial firms in the USA and Europe started with nuclear instrumentation lines, based on the experience of the Los Alamos scientists.
Some well-known names in the USA and Europe were: ORTEC, Tennelec, Canberra, ECKO, Intertechnique, Laben, Baird Atomic, Philips, MBLE…
Later on, new components were used; the semi-conductor devices (transistors) replaced the vacuum tubes during the sixties, but the circuit concepts from "Electronics" remained.
Modular instrumentation in a NIM-bin replaced the old 19" racks

Figure 9 (above). Inside view of a high voltage power supply made in 1947 by the workshop of the Nuclear Physics Lab. at Ghent University with US-army dump material

The firm MBLE (Brussels, Belgium) produced lot instrumentation for nuclear research around 1960.

Figure 10 (right). MBLE spectrometer: Single Channel Analyser with pulse amplifier, discriminator, scalers and power supply, all with vacuum tubes (150x50x40cm³)

Figure 11. MBLE preamplifier PNB 015 for scintillation detector with 3 SQ E90F tubes

The invention of the transistor at Bell Labs, NJ, USA by William Shockley (1910-1989), John Bardeen (1908-1991) and Walter Brattain (1902-1987) in 1947 allowed more complex circuits with lower power consumption and highly improved reliability.

Figure 12. The Nobel Price Laureates 1957 in Physics for the invention of the transistor. From left to right William Shockley, John Bardeen and Walter Brattain

In Belgium Bell Telephone (Hoboken-Antwerp) had a nuclear division producing advanced transistorised modular instrumentation (NUK-modules) in the early '60s.

Figure 13. Early modular nuclear instrumentation with germanium transistors by Bell Telephone Hoboken-Antwerp (1962). It contains a high voltage power supply for Geiger-Müller counters and a control unit for an angular correlation measurement set-up

Gradually transistors, field effect transistors and later on integrated circuits were used in all fields of instrumentation and NIM (Nuclear Instrumentation Modules) and CAMAC (Computer Aided Measurement & Control) became new standards in instrumentation [4, 5], until now widely used.

Figure 14. Top: low-noise preamplifier model 103 for semiconductor detectors with 6 vacuum tubes by ORTEC (Oak Ridge, TN, USA) 1969
Bottom: transistorised low-noise preamplifier with field effect transistor input stage by Princeton γ-TECH (Princeton, NJ, USA) 1971

Figure 15. NIM-modules: shaping amplifier with P/Z and BLR (TENNELEC, USA), SCA-discriminator (Nuclear Enterprises, UK) and 4 kV bias power supply for semiconductor detectors (Wenzel, D)

Introduction of computers in data handling and storage systems

The complexity of the experiments and the large amount of data lead to the introduction of computers in nuclear instrumentation in the ’70s.

ESONE (European Standard of Nuclear Electronics) developed the powerful CAMAC-standard (CAMAC: Computer Aided Measurement & Control, EURATOM 1969 [5]) between 1966-69.

A “dataway controller” couples the modules in a CAMAC-crate with a minicomputer like PDP-8 or later on a PDP-11. The data-bus concept was later on generally used in other fields of instrumentation. The CAMAC specifications have been frequently updated (FAST-CAMAC) and CAMAC modules are still widely used in large and complex experimental environments. Microprocessors (80XX, Z80, 6502) allowed build-in local calculating and control power inside the modules in the 80’s.

Another approach is the interfacing of NIM-modules (via ADC’s) with minicomputers like the PDP-15 and PDP-11 in less complex experiments.

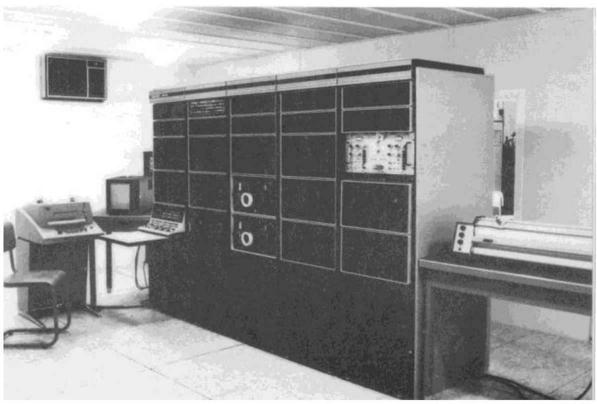


Figure 16. NIM-bin interfaced with a PDP-15/20 Digital Equipment “mini”computer (16 K core memory, TTL-logic, price €125 000) in 1972 at the linear accelerator of the Nuclear Physics Lab. at Ghent University

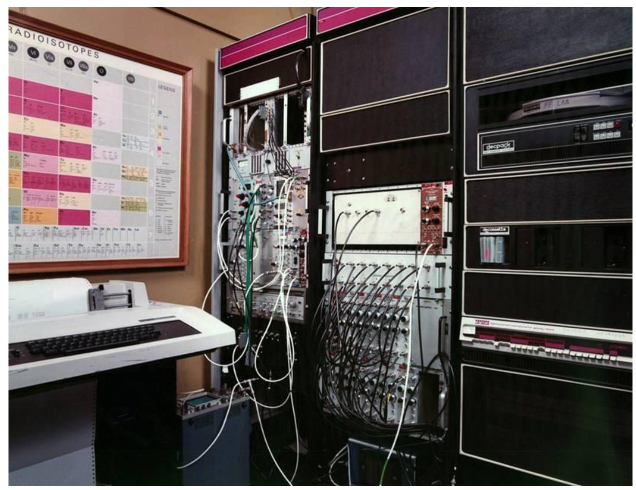


Figure 17 (right). NIM-electronics interfaced with a PDP-11 Digital Equipment computer in the 80’s at the Nuclear Physics Lab. at Ghent University (photograph by P. Dorikens, Gent)

The availability of powerful PC’s at low prices in the 90’s has virtually eliminated the use of stand-alone data acquisition systems like multichannel analysers (MCA). Special data acquisition plug-in cards for PC have been developed by various firms (ORTEC, Nuclear Data, Canberra).

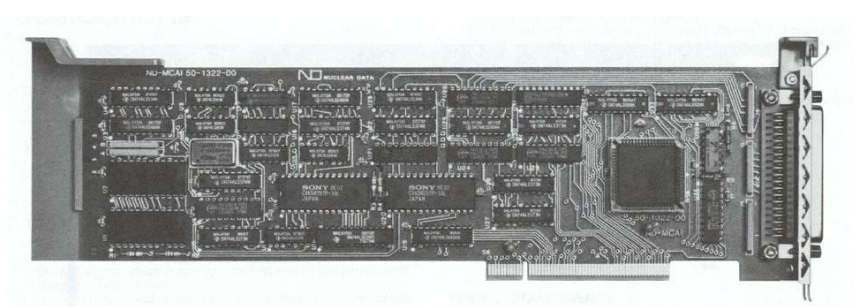


Figure 18. Data acquisition ISA plug-in card for PC by Nuclear Data Systems, Schaumburg, IL, USA

Total integration of a high resolution measuring chain for semiconductor detectors (completely digitally controlled via USB-link to a notebook PC) is recently available. The InSpector 2000 by Canberra Ind. (Meriden, CT, USA) e.g. contains a HV power supply, an amplifier with digital pulse shaping (DPS), PZC and BLR, a 16K ADC with memory and digital peak stabiliser. The dimensions are 18,5 x 17,3 x 3,8 cm³; mass 1,3 kg and the power consumption is only 3 Watt!

Figure 19. Portable spectroscopy workstation, model InSpector 2000 by Canberra Ind. (Meriden, CT, USA). This completely integrated high resolution measuring chain for Ge-detector is fully digitally controlled by a notebook PC via USB. It has 10 hours autonomy of on a standard camcorder battery pack

Other important consequences of the use computers in (nuclear) physics

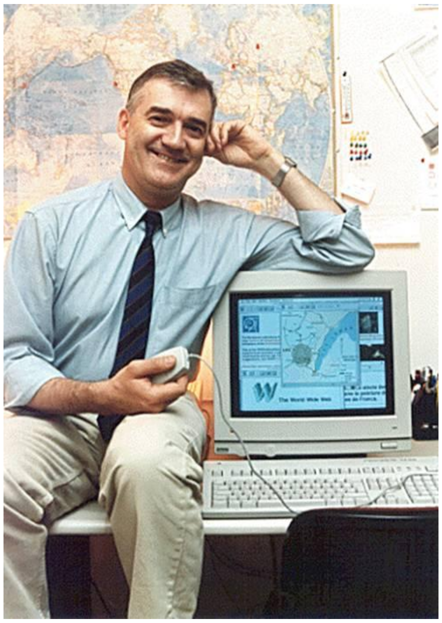
Theoretical physics and especially high energy physics were a stimulating factor in the development of "supercomputers" like the Control Data (CDC) and Cray series. The data handling division (DD) of the nuclear physics research centre of the "Conseil Européen pour la Recherche Nucleaire" (CERN) in Geneva, Switzerland played herein an important role [6].

Figure 20. Control Data CDC 6500 at CERN (ca. 1967)

Figure 21. Cray X/MP-48 supercomputer at CERN (1988-1993)

Robert Cailliau (1947), alumnus of Ghent University, and Tim Berners-Lee (1955) conceived and developed the World Wide Web (www) at CERN in Geneva around 1989-1990. The www-concept with URL and hyperlinks was primarily intended as an internal tool in CERN for data ex-change and retrieval.

Figure 22. Ir. Robert Cailliau, doctor honoris causa of UGent in 2000



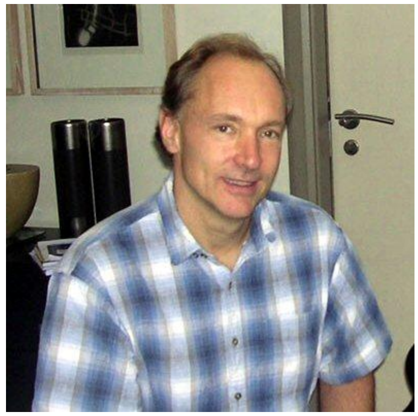


Figure 23. Sir Tim Berners-Lee

Conclusions: from radioactivity to www

Nuclear electronics has played a pioneering role in the evolution of laboratory instrumentation in the 20$^{\text{the}}$ century. The Manhattan Project during WW2 caused a real breakthrough in electronic instrumentation. The implementation of computers and microprocessors in the laboratory environment had a great impact on instrumentation and led to new and innovating applications like the World Wide Web (www – Internet).

The innovating and leading role of nuclear physics was gradually taken over by other research fields: medical instrumentation and imaging, space research, telecom (GSM), GPS etc.

A lot of the research in those new fields was conducted by physicist and engineers, trained in nuclear research and using methods originally intended for applications in that field. The modern medical imaging techniques by CT-scanning and by nuclear magnetic resonance (NMR or MRI) are striking examples of this evolution, as demonstrated by some recent Nobel Prices for Physiology or Medicine:

-The Nobel Prize for Physiology or Medicine in 1979 was awarded "for the development of computer assisted tomography" to the physicist Allan M. Cormack (1924- 1998) and the engineer Godfrey N. Hounsfield (1919-2004)

-The Nobel Prize for Physiology or Medicine in 2003 was awarded "for their discoveries concerning magnetic resonance imaging" to the chemist Paul C. Lauterbur (1929-2007) and to the physicist Peter Mansfield (1933)

Παντα ρει…

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- M.&L. Dorikens and Paul Dorikens
- Websites of the Nobel Foundation, IEEE, Wikipedia
- Catalogues and documentation from Canberra, ORTEC, Philips, DEC

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