

Agilent Acqiris Digitizers Become an Integral Part, in the Quest for Nuclear Waste Elimination

Authors: Paulo Cennini, CERN; Richard Soden, Agilent Technologies

Introduction

Researchers at CERN, the European Organization for Nuclear Research have, for some time, been investigating transmutation processes involving neutron capture. The implications this research of extend from the safe disposal of nuclear waste to the expansion of our knowledge of the origins of the Universe. These experiments are dependant upon the resolution of the neutron energies that can be observed. Using a novel experimental arrangement providing a neutron energy range that is larger than eight decades, and a bank of 64 acquisition channels of Agilent Acqiris U1063A digitizers, the researchers have pushed the limits of previous experiments to observe the neutron interactions with more detail, greater accuracy and over a greater energy range.



Figure 1. Agilent Acqiris U1063A cPCI digitizer card

Worldwide dependence on nuclear energy is diminishing. Still, today there are over 440 nuclear power reactors in 31 countries, with a combined capacity of 360 GWe. The International Atomic Energy Agency (IAEA) forecasts that the total installed nuclear capacity in 2015 will be around 370 GWe, with the nuclear share of world electricity output decreased from 17% in 1997 to 13% in 2015.

Nuclear power's biggest drawback has always been the resultant waste. With the current number of installations, over 250,000 tons of spent fuel from reactors will require eventual disposal. This is predicted to increase to over 1 million tons by the middle of the 21st century. Efforts are rightly focussed on methods that reduce the amount of waste produced and decrease its toxicity to the environment.

Nearly all issues related to the risks arising from long-term disposal of radioactive waste are attributable to ~1% of its content. Made up primarily of plutonium, neptunium, americium, and curium and long-lived isotopes of iodine and technetium, these so called long-lived fission fragments (LLFF) are created as



products from the fission process in power reactors. A few of these products, such as technetium-99 and iodine-129, have very long radioactive half-lives (200,000 years and 15 million years, respectively). It is impossible to assure the risk-free disposal of such elements to future generations over such large time scales.

Reprocessing spent nuclear fuel involves using a chemical process to separate out plutonium and fissionable uranium from spent fuel rods. This process can reduce the volume of waste material. However, the byproduct of reprocessing remains high-level waste which requires proper disposal.

Commonly this highlevel waste is mixed with a hot glass material and solidified. This glassification process makes it easier to transport and store the nuclear waste at geological disposal sites.

An alternative, or complementary, technique for safe disposal of this waste is the suggested transmutation processes. Transmutation refers to any process that involves changing radioactive elements into generally shorterlived, or even stable, substances. Transmutation occurs naturally in radioactive decay, through spontaneous fission, fusion, neutron capture, or numerous other processes, but this decay rate can be increased by methods that induce these processes to occur more frequently than would be seen in nature.

Researchers at CERN, the European Organization for Nuclear Research, have been researching such processes in the form of Transmutation by Adiabatic Resonance Crossing (TARC) for some years. This Accelerator Driven System (ADS) increases nuclear decay rates by optimizing the neutron capture rates in the radioactive target materials. The European Commission approved within the 5th EURATOM programme the n_TOF-ADS-ND project. The main advancement of the state-of-the-art offered by this

“Using Acqiris digitizers allowed the n_TOF research team to carry out the neutron capture experiment exactly how it was envisaged. With long internal memories, high clock accuracies and useful data reduction procedures, the digitizers were exactly what we needed”.

Paolo Cennini

n_TOF Technical Coordinator, CERN



experiment lies exactly in the dissemination of a complete and consistent set of high accuracy cross-sections, extending over eight orders of magnitude in the neutron energy and satisfying the demanding research and industrial requirements presented in realworld application. Due to the flexible configuration of the CERN accelerator complex and the innovative technological concepts that are exploited within the n_TOF project, the quality of the measurements in this facility is superseding that of those at any other neutron source.

The neutrons used in the n_TOF experiment are created, through spallation, by placing a lead block in the path of a 20 GeV/s proton beam, taken from the CERN Proton Synchrotron (CERN PS). Lead, as a spallation target, offers a large neutron yield (600 neutrons/proton at 1 GeV) and is principally transparent to the neutron. However, elastic and inelastic collisions within the lead block result in a useful broadening of the energy spectrum of the emergent neutrons. Depending on the path taken through the lead block by the neutron and with the addition of a hydrogen rich neutron moderator, it is possible with this system to produce a neutron beam with energies from 1 eV to 1 GeV.

In the n_TOF experimental arrangement a collection tube, with a length of 200 m, is placed after the lead block, off axis to the incoming proton beam (Figure 1). At the opposite end of the tube is placed the sample material and wave and charged-particle detectors connected to the associated data acquisition system including 64 channels of Acqiris high-speed digitizers. The purpose of the collection tube is to avoid dispersion in the results by limiting the neutrons that arrive at the final target to those which travel directly along that 200 m path of the tube.

Several n-TOF measurements are also of interest in the field of Nuclear Astrophysics. Astrophysics is approaching a stage where a number of longstanding central questions about our universe can finally be addressed with such techniques. In describing hot big bang cosmology (using the so-called standard model), the quest for the origin of the chemical elements plays a prominent role: In particular, the production of ^2H , ^3He , ^4He and ^7Li (200 s after) in the big bang bears important consequences for cosmology and particle physics. By precisely measuring the neutron induced reactions of specific isotopes at the n_TOF experiment it is possible to obtain new data to understand how these elements were created after the big bang.

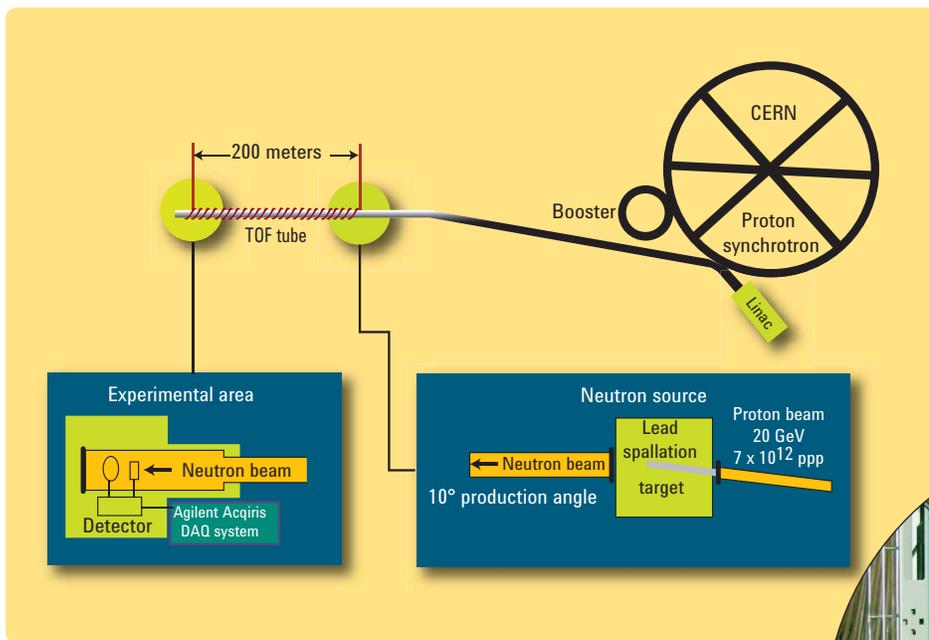


Figure 2. General layout of the n_TOF experiment

Protons from CERN PS arrive at the lead target at a pulse rate of 0.33 Hz, each pulse containing up to 0.7×10^{13} protons, over pulse durations of 6 ns rms. Spallation at the lead block results in a flux of produced neutrons at the opposite end of the collection tube of 8×10^6 neutrons/ pulse. As a consequence to the 200 m length of the collection tube, high-energy neutrons of 1 GeV, travelling at close to the speed of light, arrive at the sample material after only 600 ns. Lower energy neutrons arrive after this with a delay that is inversely proportional to their energy, such that a neutron of 1 eV will arrive at the target after approximately 15 ms. The neutron energy resolution varies from 0.03% at 1 eV up to 2% at 1×10^8 eV with a typical value of 0.1% at 3×10^4 eV.

The acquisition system consists of 8 clusters of 8 acquisition channels each possible of sampling at 1 GS/s, each channel with 8 Mpoints of memory (Figure 2). Each cluster is managed by a high-performance embedded processor at 1 GHz with 1 GB DRAM and 40 GB HD connected to a network through a 1 Gbps ethernet interface to collect and rapidly store the data. The system is triggered on the incoming proton pulse from the CERN PS. Measurements are made over a gate width of 15 ms (to accommodate all the neutron energies in the range 1 eV to 1 GeV/s), sampling all 64 channels at 500 MS/s.

Obtaining simultaneous measurements from the 64 digitizer channels, experimental measurements are based on the detection of prompt events, in the form of waves or charged particles generated by the sample under test and detected by various equipment. The associated incident neutron energy is determined through the Time Of Flight (TOF) measured with a time resolution better than 10 ns (limited



Figure 3. High-speed data acquisition system

by the initial proton pulse width). The results obtained in the n_TOF experiment show a marked increase in the energy resolutions obtained (Figure 3). From the graph shown for the $^{236}\text{U}(n,f)$ cross section, previous measurements showed only one resonant peak at around 1290 eV of 150 mb, and peak width of around 30 eV. With the improved energy resolution provided by the use of the Acqiris digitizers, the cross-section distribution in the measurements observed at n_TOF show in fact three resonances at 1270 eV, 1280 eV and 1290 eV, with the same area as the one shown in the previous data. Each resonant peak shows an improvement in the peak width by a factor 10, and now shows to be of the order of 3 eV.

The measurements at the CERN n_TOF facility are currently producing experimental cross section data for the critical task of neutron cross section theoretical evaluation, and the development of an advanced software system for the storage and dissemination of these results, in the form of a database specifically for ADS. The improved energy resolutions provided at the n_TOF experiment are leading to both a better understanding of the origins of the universe and the elements that compose it, and also the development of more efficient transmutation methods for the safe disposal of nuclear waste.

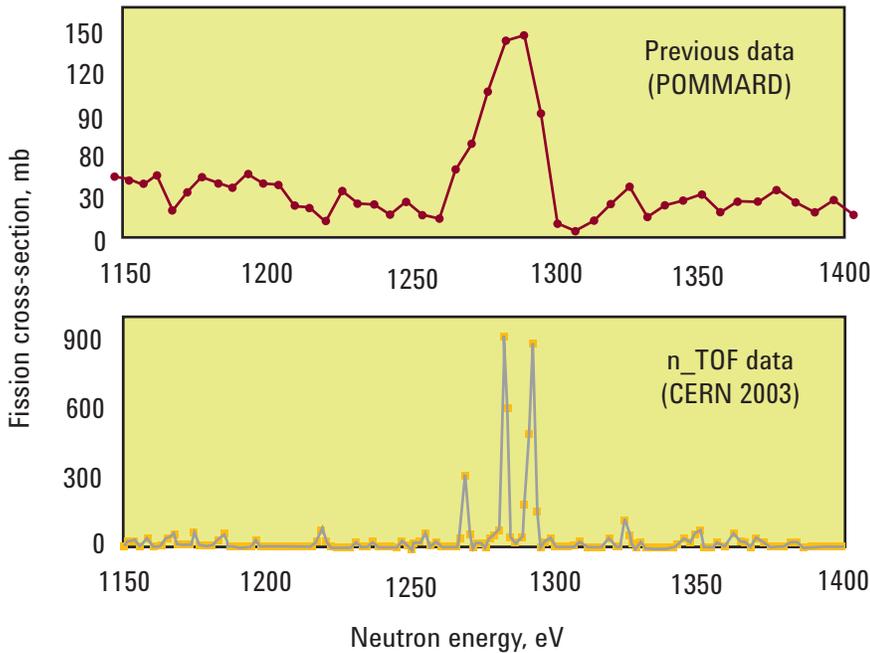


Figure 4. Comparison between data measured at n_TOF with previous data for $^{236}\text{U}(n,f)$ cross-section

"This picture shows the quality of the n_TOF facility in terms of resolution measured thanks to the accuracy of the Agilent Acqiris modules".

Paolo Cennini

n_TOF Technical Coordinator, CERN

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USA	(845) 782-6544
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