Performance of ADONIS-LYNX System for Burn-up Measurement Applications at AREVA NC La Hague Reprocessing Plant

Eric Barat, Stéphane Normand, Thomas Dautremer, Jérémie Lefevre, Cédric Herman, Nabil Menaa, Michael Shen, Gabriele Grassi

***Abstract* — This work deals with the last measurement campaign done at the AREVA NC La Hague reprocessing plant with the new industrial ADONIS system called ADONIS LYNX. In this paper we briefly explain the ADONIS bimodal Kalman smoother. Next, we present the experimental set-up as well as the industrial approach for the ADONIS system. Results from measurement campaign are then discussed. Some ways of improvement are also explained.**

***Index Terms*— HPGe spectrometry, digital signal processing, ADONIS system, gamma passive assay.**

I. Introduction

ADONIS (Algorithmic Development FramewOrk for Nuclear Instrumentation and Spectrometry) is a digital system for gamma-ray spectrometry, developed by CEA and AREVA NC. With the development phase completed, ADONIS system industrialization has been tackled by CANBERRA [1,3]. Thus, a test campaign has been settled at the burn-up measurement station of AREVA NC La Hague spent fuel reprocessing plant. High Purity Germanium detectors, type P and N, have been used to measure burn-up level for spent fuel thanks to the Cs-137 to Cs-134 concentration ratio [5]. This result is very important for each subsequent process undergone by spent fuel assemblies.

In the first part of the paper, we introduce the experimental set-up as well as explain the mean ADONIS performances and the mathematical approach undertaken with ADONIS. The measurement station is also described. Two kinds of collimators are used: one fixed and one mobile. We have chosen to open the mobile one at the maximum entrance level in order to maximize count rate statistics on the sensor side.

ADONIS-LYNX system consists of a high frequency digitizer coupled with a Kalman smoothing filter. Given the current state-of-the-art FPGA (Field Programmable Gate Arrays) technology, this algorithm still cannot be implemented in firmware [2,4]. Consequently, signal processing must be done in software. For the industrial ADONIS version, the digital link between digitizer and PC is achieved through a USB 3.0 connection. ADONIS algorithm runs on a Linux machine, making both saving data in list mode and plotting data after processing possible.

In the second part of the paper, data are analysed and performances of the historical ADONIS system are compared with the industrial ADONIS-LYNX System. Results have been analysed by the aspect of reliability on the Caesium ratio computation. Precision achievable by the method is also discussed.

In conclusion, this paper reports the capabilities of the industrial version of ADONIS [1,4] operated in a realistic industrial environment. Other applications that can benefit from list mode data format provided by the ADONIS-LYNX system are also discussed [7].

The measurement campaign demonstrated that the whole measurement system is suitable for industrial set-up and can provide much more information than the current measurement system. Therefore, plant operation can potentially gain in flexibility and processing time.

II. Experimental Set-up

A. Burn-up Measurement Cell

The burn-up facility at AREVA NC plant is composed of two HP-Ge crystals. For the purpose of our measurement, one of the two Germanium crystals has been coupled with a transistor reset preamplifier. In fact, transistor reset preampfliers are preferred for high counts rate experiments.

The collimator is made of two sub-systems; a fixed opening of 10mm, and a mobile one so that an aperture up to 10mm x 10mm can be used.

Once the fuel rods have been chosen for being reprocessed, they have to be measured for safety reason in order to determine the residual fissile mass before shearing the

Eric Barat, Stéphane Normand are with the CEA, LIST, Laboratoire Capteurs et Architectures Electroniques, F-91191 Gif-Sur-Yvette, France (corresponding author e-mail: stephane.normand@cea.fr).

Jérémie Lefevre is with the AREVA NC La Hague F-50444 Beaumont Hague, France.

Cédric Herman and M. Shen are with the Canberra Inc, 800 Research Parkway, Meriden, 06450 CT, USA.

Nabil MENAA is with the Canberra France, 78 Montigny-le-Bretonneux, France.

Gabriele GRASSI is with the AREVA NC La Défense, F-92084 Courbevoie, France

assembly. This is the aim of this measurement set-up. Currently the existing system operates properly and the objective of this work is to improve the speed and the accuracy of this measurement.

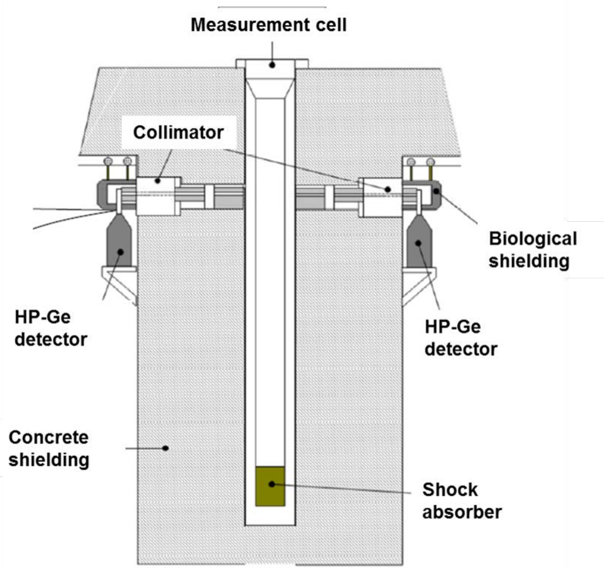

Fig. 1: Schematic view for the burn-up measurement cell, called station 1

The aperture of the collimator is chosen in order to maintain a total count rate achievable by the existing electronic chain. For our testing purpose, we have chosen to open at the maximum the aperture which can lead to have only one fixed collimator for all fuel when using ADONIS-LYNX.

Station 1 is mainly based on gamma-ray spectrometry. Once the collimator aperture is computed from fuel data, the moving crane inserts the assembly fuel into the measurement cell. The fuel goes down and gamma ray scanning is performed.

The burn-up is then calculated as mentioned on Eq. 1. Alpha and Beta are calibration parameters depending on the type of fuel measured [6].

$$BU = \alpha \frac{^{134}Cs}{^{137}Cs} + \beta$$

Eq. 1: Burn-up formula

The first goal of our measurement is to show that in case of low burn-up and/or long cooling time the Cs-134 activity measurement is still possible. The second objective is to be able measuring high burn-up fuel with low cooling time, that induce in fact high count rates at this measurement cell. In fact, the Cs-134 half-life being only 2.65 years, its activity may be lower that the detection limit in case of long cooling times (starting from 20 years). The acquisition time is also limited to 20 minutes adding another constraint on statistical significance to determine the activity

B. ADONIS system

ADONIS is a digital system capable of handling very high count rate up to 3.10^6 events per second as well as maintaining spectroscopic information when the count rate varies.

It is designed to maximize the output count rate and achieve a real time metrology, even in high count rate environment with variable activities.

The historical ADONIS system was packaged in a NIM module, which consists mainly of a 20-MHz digitizer with 14-bit resolution. The no-linear filtering algorithm relies on a bimodal Kalman smoother which is based upon the maximum likelihood principle. A real-time implementation has been done on a PC that is connected directly to the front-end digitizing electronics.

Fig. 2: Photo of the historical version of the ADONIS system

The design is almost 12-year old and needs to be maintained with an up-to-date readout electronic. However, the algorithmic approach for the ADONIS signal processing is still the same and gives, even 12 years after the first benchmark, good results in terms of both resolution and maximum count rates achievable.

C. Industrial Version

Thanks to its USB3.0 communication link, the ADONIS industrial version is suitable for a versatile use.

Fig. 3: First industrial prototype of the ADONIS-LYNX system

The front-end electronics is an upgraded version of the LYNX Digital Signal Analyzer, already commercially available from CANBERRA Industry.

The algorithms and software have been designed by CEA and handle all previous ADONIS design.

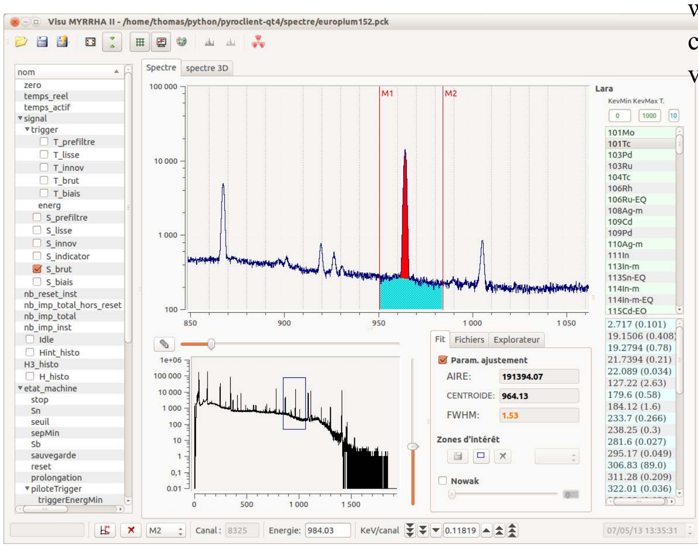

Fig. 4: GUI for ADONIS system.

Figure 4 gives a snapshot of the Graphical User Interface of ADONIS-LYNX system designed by CEA. Some algorithm parameters should be tuned for the first time, but afterwards it is not necessary for the operator to change any of them even from low count rate up to the maximum count rate.

III. Measurements

All the measurements have been done with two fuel assemblies, one with a high burn-up and a short cooling time (in order to maximise Cs-137 activity and thus count rate) and another one with low burn-up and long cooling (in order to minimise Cs-134 activity and count rate). The aim is using both fuels to be able to cover a wide range of fuels that may be processed at La Hague.

The detector was a High Purity Germanium N type from former Eurisys Mesures Company coupled with a transistor reset preamplifier. The applied high voltage was -3600 Volts. All the electronics devices have been installed a few meters away from the Germanium diode. Indeed, the distance between the preamplifier and the front-end electronic was less than 6 meters.

A robot introduces the fuel assembly inside the measurement cell at a pre-selected speed, either low (which is standard for measuring a fuel in 20 minutes) either fast (which is experimental and dedicated to these tests)

The measured resolution obtained with a Cs-137 lab source of 415 kBq (as of 02/04/1990) is 1.46 keV for ADONIS-LYNX and 1.37 keV for historical ADONIS version.

For the high burn-up fuel, the estimated activity is about 2700 TBq from the Cs-137 line. It means that during the experiment several million counts per second were recorded.

IV. Results

Figure 5 shows the total gamma spectrum obtained after a whole fuel scan. On the right of the figure, we can notice, centred on the Cs-137 peak, the variation of the count rates versus the z-axis of the fuel.

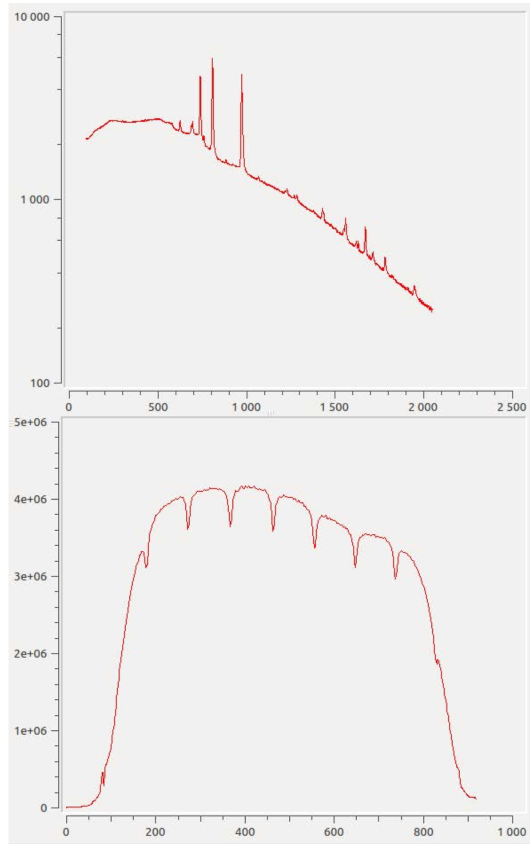

Fig.5: Total gamma spectrum (top part); and Activity on Cs-137 peak versus the z-axis of the fuel (bottom part). The z-axis scan was obtained at low speed.

Figure 6 confirms the ability of the ADONIS-LYNX system to measure all the activity variation from the starting up to several million counts per second without any tuning from the operator. The right sub-figure shows the variation of the Cs-137 peak versus the z-axis. One can notice that even space grids (generating a slight activity decrease) could be observed. The curve shows also an image of the neutron integrated flux seen by the fuel during its life in the reactor core.

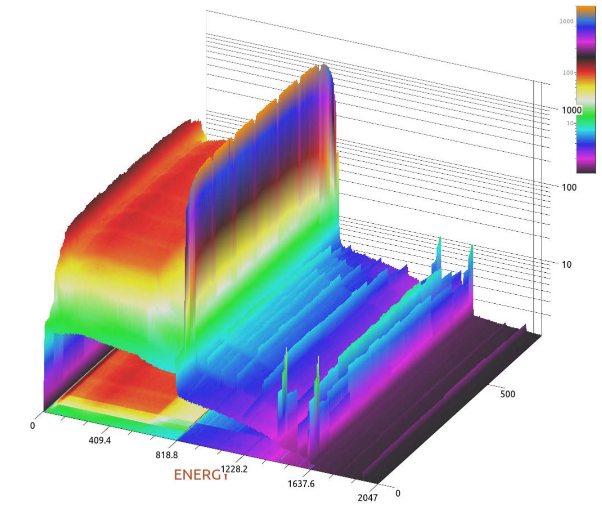

Fig. 6: A 3D scan obtained at low speed. Energy is given versus the z-axis and the count rate.

Figure 7 shows a typical 3D spectrum obtained after a scan of 20 minutes, which is the standard approach at the AREVA NC La Hague plant. This spectrum has to be corrected from the dead time given by the ADONIS system.

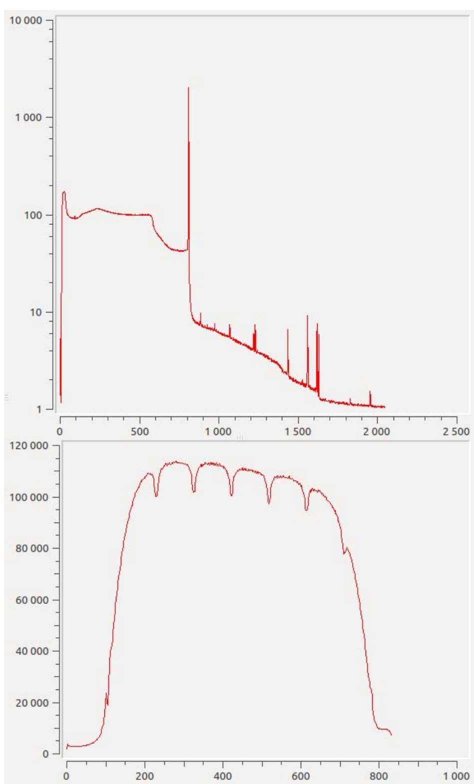

Fig. 7: Total gamma spectrum obtained after a whole scan (top part); and evolution of the Cs-137peak versus the z-axis of the fuel (bottom part). The full scan was obtained at high speed.

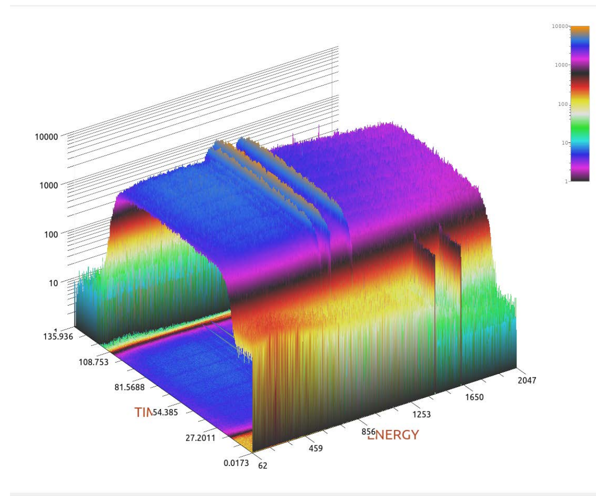

Fig. 8: A 3D scan obtained at high speed. Energy is given versus the z-axis and the count rate for the low burn-up and long cooling time fuel

Even if the gamma spectrum degrades with speed, this experiment shows that it is possible to obtain valuable data at high speed, mostly due to the aperture being fully opened and thus increasing statistics.

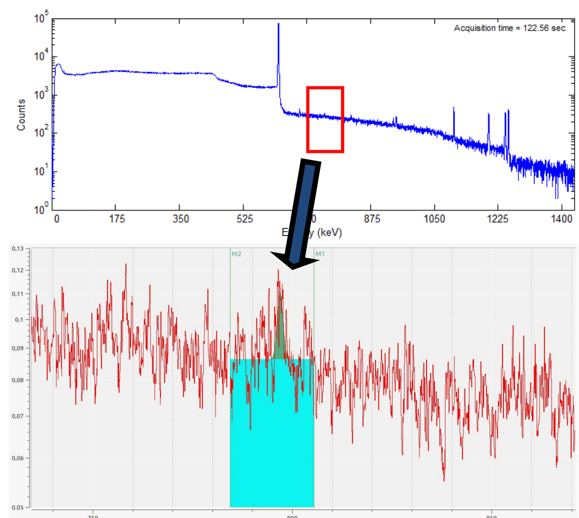

Fig. 9: A 3D scan obtained at high speed. Energy is given versus the z-axis and the count rate for the low burn-up and long cooling time fuel

As shown on Figures 9 and 10, extracting the Cs-134 signal at high speed is harder than at low speed, but it is still possible. For all of these measurements, the mobile collimator was fully opened (10mm x 10 mm).

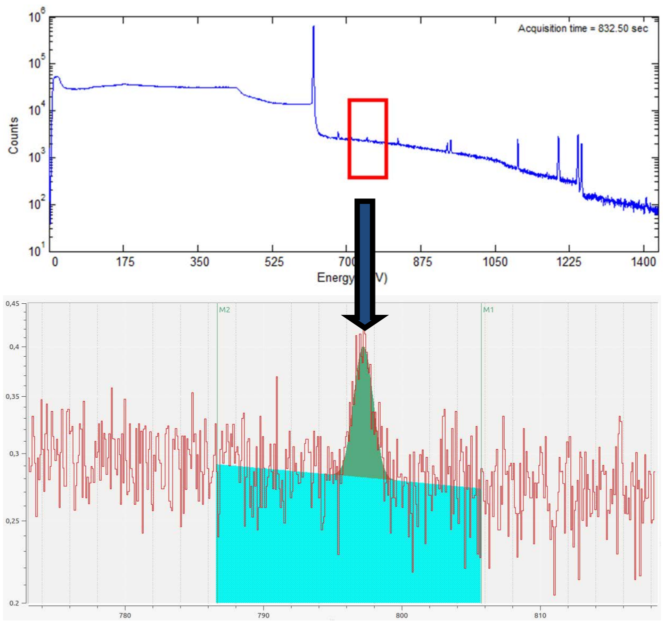

Fig.10: Spectrum obtained for high burn-up fuel, standard acquisition speed.

A. Measurement Analysis

Table I shows mean results obtained for several apertures of the collimator. We can notice clearly that the resolution degrades when the input count rate increases. However, using ADONIS-LYNX system, the loss in terms of resolution is lower than for the installed analog electronic chain.

TABLE I: MEASUREMENT COMPARISON FOR LOW COUNT RATES

Collimator Opening (mm × mm)	Input Count Rate (cps)	keV FWHM @ 662keV		Dead Time (%)	
		Standard Analog	Adonis-Lynx	Standard Analog	Adonis-Lynx
10 × 0.7	~18,500	11.72	1.55	9.0	N/A
10 × 2	~143,000	32.04	2.19	64.4	N/A

Using data from the standard analysis system versus the Cs-134 and Cs-137 ratio obtained by ADONIS-LYNX, we observed a difference less than 0.24 ‰ which is an excellent result. For low burn-up fuel assembly, we did not obtain a valuable measure from the standard acquisition system; therefore there was no really value for the burn-up of this fuel.

V. DISCUSSION–CONCLUSION

This industrial ADONIS version was fully checked during this measurement validation work. Therefore, it makes it possible for CANBERRA to build and sell ADONIS-LYNX modules for its customers. ADONIS approach is therefore suitable for industrial measurement in its industrial version.

The theoretical approach is enough robust to be adapted to another digitizing platform not specifically design for it.

The ADONIS LYNX system enhances so the working domain for this measurement cell. Then operators can manage handling easily high or very low burn-up fuel.

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