

### Use of PFTNA for On-Line Coal Analysis

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## INTRODUCTION

This study deals with the development of a prototype real time coal analyzer based on Pulsed Fast Thermal Neutron Activation (PFTNA) technique. The measured parameters are calorific value, amount of ash, sulfur, and moisture. The feed of coal with uniform characteristics is essential for better performance and this feed is arranged with the proper mixing of well classified raw materials. This analyzer will be utilized for the characterization necessary for the classification process.

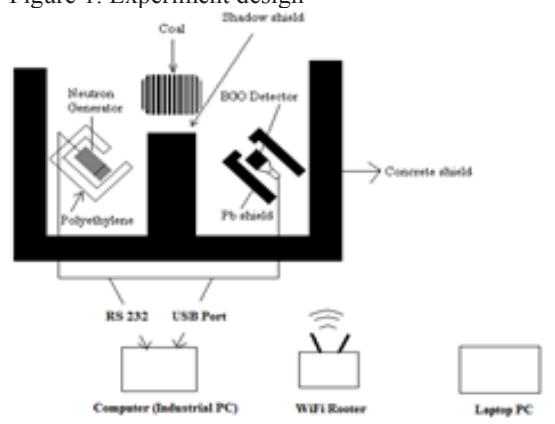
## DEVELOPMENT OF A PROTOTYPE FOR THE ON-LINE ELEMENTAL ANALYSIS OF COAL

The method is based on the irradiation of coal with neutrons while the coal is transported on a conveyor belt. Neutrons irradiation results in the coal activated and emission of gamma rays. For the on-line coal analysis, Pulsed Fast Thermal Neutron Analysis (PFTNA) technique is utilized. This method gives precise results even in a short period of time. Several elements are detected from the reactions occurred by fast or thermal neutron interactions. Therefore, it is needed to use both fast and thermal neutrons in the process.

## Monte Carlo Simulation

MCNP (Monte Carlo N-Particle) software package [1] was used to check the geometry of experimental setup and nuclear interaction mechanisms. The geometry of the experimental setup is represented in Figure 1.

Figure 1. Experiment design



This figure shows the top view of the experimental setup. According to this geometry, gamma rays are emitted as a result of neutron interactions with coal. These gamma rays have characteristic energies representing the elements in the coal. The peak energies are calculated first and the corresponding elements are identified. The results of the Monte Carlo simulation are represented in Figure 2 as an example spectrum obtained by BGO (Bismuth Germanium Oxide) detector. Also MCNP simulation element spectra are used to evaluate the unknown coal spectrum.

## Analyzing Prompt Gamma Spectrum for Element Calibration

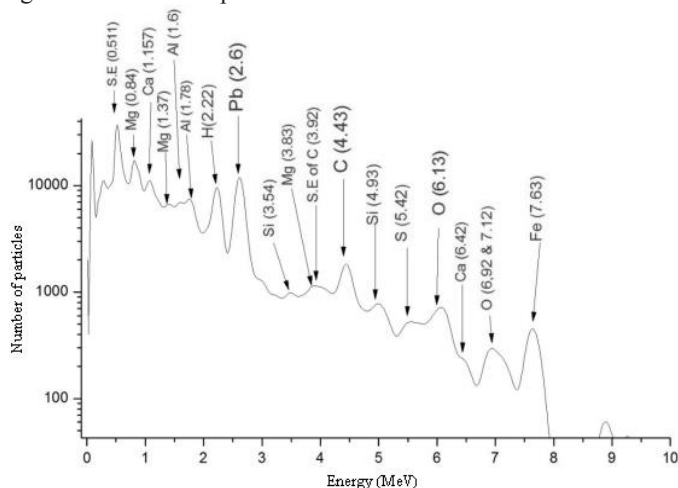
On-line analyzer must be calibrated with coal standards that range from 5 to 40wt% ash levels and calorific values with total carbon of 40-80 wt%. It was focused on the library least square (LLS) approach to analyze the experimental prompt gamma spectrum obtained with low resolution BGO detector [2]. This method is capable of analyzing spectrum with unsolved peaks. In this method, the elemental library spectra are needed solving the unknown coal spectrum with non-linear effects. Two approaches can be used for finding the element libraries. One approach is to use experimentally measuring library spectrum for each element, the other one is to obtain by using Monte Carlo library least squares (MCLLS) [3]. In this study, the MCLLS approach which is used standard element spectra is preferred, and element library is developed by using experimental element spectra [4]. The studies on “hybrid method” have been continued in ITU Energy Institute. Hereby unknown coal spectrum is evaluated with linear sum of the library spectra of known elements. Peak energies corresponding to the centroids are used to label representative elements in the spectrum.

## Experimental Studies

The coal is irradiated by neutrons generated by a Thermo Neutron Generator MP320 (NG) which produces 14 MeV isotropic neutrons. They are slowed down by interacting with the materials in the medium. As a result of nuclear reactions, gamma rays are collected by a BGO detector. During the irradiation process of the coal, both fast and thermal neutrons give rise to  $(n,\gamma)$  reactions to occur. Recording of fast and thermal neutron spectra are conducted with NG operating in the pulse mode. NG produces fast neutrons with 10 $\mu$ s pulse duration and 10 kHz frequency. Source pulse of the NG ([5] VDC, TTL

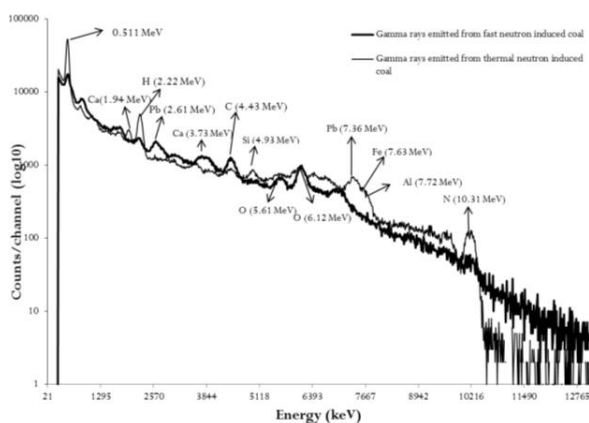
signal) is connected to the detector gate terminal. Figure 1, experimental data acquisition system is sketched. NG and BGO detector are both connected to the computer via RS232 and USB ports, respectively.

Figure 2. PFTNA output of MCNP



Since constituent elements of the coal have certain energies belonging to fast neutron or thermal neutron derived gamma, total spectrum should be separated. This sorting is realized with the aid of a C++ software code. The data obtained during the experiment are in the format of the "list mode". Because of this data format, the data are in raw form and consequently dead time is minimized.

Figure 3. Set-1 Coal spectrum



The experiment is conducted with coal samples with various chemical compositions. There are 8 sets of coal samples. The selection is made to cover a wide range of compositions out of the coal samples from the Aegean region of Turkey. After the experiment is conducted, "list mode" file is decoded and analyzed by using C++ code. Figure 3 shows the spectrum obtained for one set of coal sample after they are sorted and classified as fast and thermal neutron derived gamma counts.

## RESULTS

Figure 3 shows that some of the elements in coal should be identified by analyzing fast (C, O) or thermal neutron prompt gamma spectra (H, S, Mg, Al, Si, Fe, Ti, Ca). MCA with 1024 channels are set up to 10 MeV gamma energy. In addition, thermal neutron gamma ray counts are more than fast neutron prompt gamma counts due to the fact that pulsed mode duration of NG is longer for thermal neutron output. By using these results, elemental response functions found with MCLS approach are developed by de-convoluting a number of sample spectra (8 coal samples) with preset element contents. Since some of the Gaussian peaks overlap, each of the constituent element of coal cannot be easily separated. Therefore, spectrum unfolding method is used by utilizing a FORTRAN code. After all of the responses are obtained, element coefficients are calculated with Multiple Linear Regression (MLR) technique. These response functions are fitted to the experimental coal data. These coefficients are used for the calibration of the system. For this process, it is used an analyzed coal sample with known chemical composition in advance. Calibration coefficients are found in this stage of the study. These values are checked for validation process, and then, these coefficients are used for any unknown bulk materials. In conclusion, the moisture, ash and elemental content of a coal material are found. Calibration and validation studies have been going on using standard coal samples with different element contents.

## ACKNOWLEDGMENT

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## REFERENCES

1. X-5 Monte Carlo Team, "MCNP - A General N-Particle Transport Code, Version 5", Los Alamos Laboratory, USA
2. L. DEP, M. BELBOT, G. VOURVOPOULOS, S. SUDAR, "Pulsed Neutron-Based On-line Coal Analysis", *Journal of Radio analytical and Nuclear Chemistry*, **234**, 107 (1998)
3. L. J. MENG, D. RAMSDEN, "An Inter-comparison of Three Spectral-Deconvolution Algorithms for Gamma-ray Spectroscopy", *IEEE Transactions on Nuclear Science*, **47**, 691 (2000).
4. R. P. GARDNER, L. XU, "Status of the Monte Carlo library squares (MCLS) approach for non-linear radiation analyzer problems", *Radiation Physics and Chemistry*, **78**, 843 (2009)
5. H. WANG, J. LU, Y. LU, D. YANG, K. MA, K. YANG, Y. LIU, D. CHENG, "An Experiment-library least squares method on on-line coal element content analysis", *Science China*, **55**, 2062 (2012)