Using On-line Nuclear Elemental Analyzers to Optimize Boiler Operation at Choctaw Generation Station in Northeast Mississippi

Steve Foster
Vice President Product Development; SABIA, Inc.
Mike Heger
Senior Mining Engineer; North American Coal Red Hills Mine

Abstract

In fiscal 2001 the Choctaw Generation Limited Partnership put into operation a 440-megawatt power production facility in Northeast Mississippi. The operation is a state-of-the-art facility using clean coal technology to burn lignite coal mined near the plant by North American Coal. The power plant uses twin fluidized bed boilers to generate the steam used to create the power ultimately delivered to TVA. In keeping with the advanced technology used in the original design of the facility, an on-line nuclear elemental analyzer** has been added upstream of the boilers to ensure optimum operation. This paper will take a detailed look at the application and provide data on the benefits of the technology to minimize boiler shutdown and optimize boiler performance.

** Nuclear Elemental Analyzers as defined for the purposes of this paper are those analyzers that measure the individual elements of the periodic table. For example, Ash is determined by adding the sum of the individually measured constituents of Ash, i.e., Silicon, Iron, Calcium, Aluminum, Potassium, Titanium, etc…

Introduction

The Choctaw Generating Station is a 440 megawatt (net) lignite-fired power plant located in Choctaw County in northeast Mississippi. Construction of the plant began in 1999 with full commercial operations being achieved in 2002. It is owned and operated by Suez Energy International under a 30 year base load contract with the Tennessee Valley Authority (TVA).

The plant utilizes 2 Altstom circulating fluidized bed boilers to provide steam to a single Toshiba turbine. At the time of construction, Choctaw Generation had the largest CFB boilers in North America. The plant was designed and currently meets EPA phase 2 regulations with NO_X limits of 0.20 lbs/mmbtu and SO_X limits of 0.25 lbs/mmbtu. The entire output of Choctaw Generation is dedicated to TVA.

Figure 1. The Plant Layout

Lignite to fuel the power plant is provided by the adjacent Red Hills Mine. It is owned and operated by the North American Coal Corporation. The Red Hills Mine was permitted and constructed in conjunction with the Choctaw Generating Station and is the only coal mining operation in the state of Mississippi. The fuel sales contract between North American Coal and Suez Energy is an all requirements contract which runs concurrently with the 30 year contract between Suez Energy and TVA. On an average year Choctaw Generation will burn 3.6 million tons of lignite.

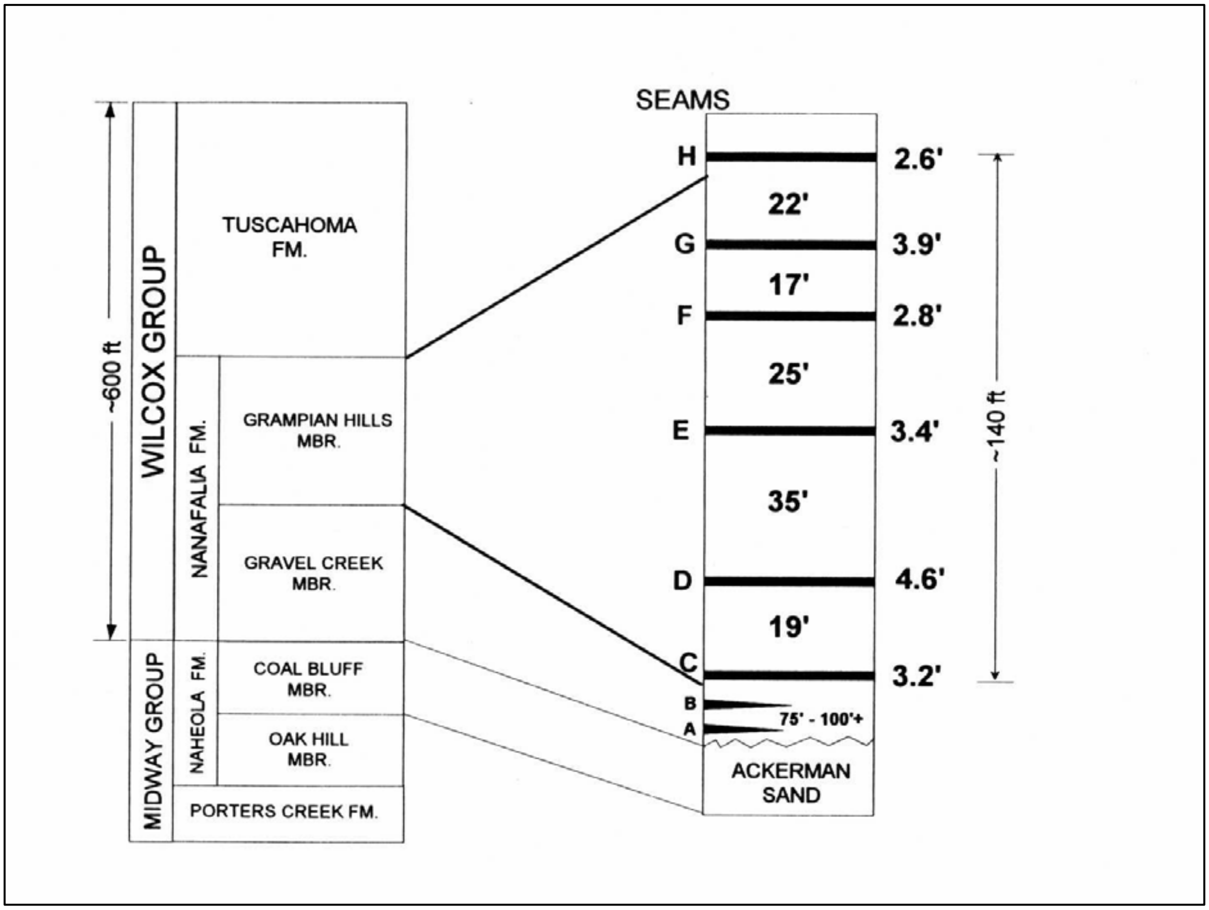

Figure 2. Coal Seams at Red Hills Mine

Lignite at Red Hills is found in six thin seams. Individual seam thicknesses range from 6" to 60". Each seam is separated by silty clay interburdens ranging in thickness from 10' to 40'. Covering all of this is an overburden with thicknesses ranging from 20' – 150'.

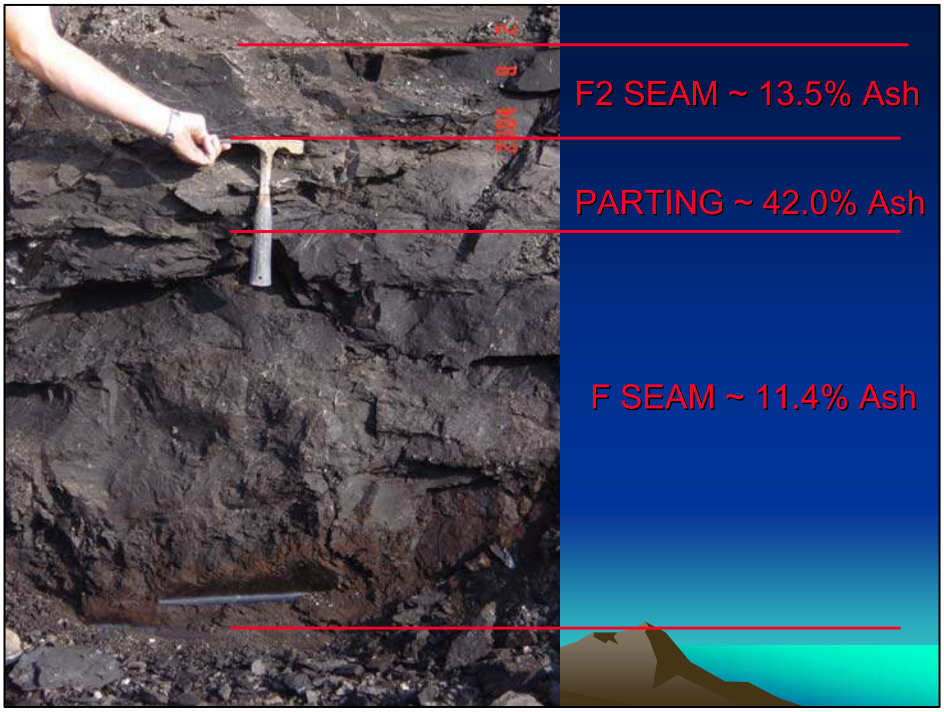

Figure 3. The Parting Problem at Red Hills Mine

The mining process at Red Hills has been characterized by mining professionals as among the most complicated in North America. It begins with and an electric rope shovel and a fleet of 200 ton trucks stripping the top overburden layer and hauling it around to the back of the pit as fill for final reclamation. This uncovers the first lignite seam. The next three lignite seams are uncovered by a fleet of dozers pushing the interburdens into the previous empty pit. The final two seams are uncovered by a spoil side dragline operation. Adding to the complexity of this operation is the annual rainfall of 68" that the mine has experienced since its opening.

The lignite in Mississippi is a very low grade coal. The most dominant characteristic is its high moisture content. The average moisture of the lignite at Red Hills is 42.5%. This high moisture greatly diminishes the BTU value of the coal. The BTU at Red Hills averages 5180 BTU/lb. Average values for ash and sulfur are 14.6% and 0.6% respectively.

The Choctaw Generating Station and the Red Hills Mine are two independent businesses whose individual success is dependent on the performance of the other. The generating station was built to partially address the future electricity needs of TVA customers. The location of the generating station was chosen, in part, because of its proximity to an abundant, clean, low-cost fuel supply. In simple terms, the Red Hills Mine would not exist without the Choctaw Generating Station and the Choctaw Generating Station would not exist without the Red Hills Mine.

These facts have been realized by the key management of both organizations and contributes to a very cooperative relationship between the two. This relationship creates an environment where problems that plague the mine and the power plant can be addressed creatively through the combined resources of both organizations without the need for unnecessarily assigning blame. This relationship works to the benefit of both parties and is something that unfortunately is all too uncommon in our industries.

Figure 4. Primary Crusher and Feeder – C1 Conveyor

Lignite from the mine is delivered to a 400 ton hopper. From the Hopper it is crushed using a Stammler feeder breaker and transferred to the C1 conveyor. C1 is a 60" wide belt which contains a process scale and a tramp metal detector.

Figure 5. Coal transfer points before the generation plant

Following the C1 Conveyor is the C2 conveyor. C1 and C2 are constant speed belts which results in variations of coal thickness as feed rates through the Stammler feeder breaker increase or decrease. Varying thicknesses of coal on a conveyor can be a considerable source of error for any cross belt coal quality analyzer. For this reason these devises generally incorporate belt scale information or some other means of estimating the thickness of coal on the belt. In the case of the dual gamma ash and microwave moisture meters that were located on C2, the vendor chose to utilize their own proprietary technology as a means of correcting for coal thickness variations. In the end this did not work as well as anticipated and the inability to properly measure coal quality at different feed rates became one of many reasons the dual gamma ash and microwave moisture meters were later removed.

At the end of the C2 conveyor, coal is either fed directly into Euro-silo #2 or transferred to conveyor C3 where it is then fed into Euro-silo #1. Each Euro-silo contains a complex system of chutes and augers that results in coal being placed in the silos in layers. As coal enters the silo it is pushed to the outer edges of the silo. By doing this there is no coning effect that is observed in more traditional silo operations. When the silo is emptied the coal is removed via the same layering methods that were used to fill it. This mode of silo operation presents some interesting challenges and opportunities with regards to the implementation of PGNA technology.

In many cases, PGNA analyzers can be used in conjunction with flop gates to sort coal going into various silos or piles. In order to do this a certain degree of agility is required on the part of the coal handling system. Unfortunately, euro-silos operating in a fill mode simply do not have that degree of agility which eliminates the possibility of incorporating any type of sorting system based on analyzer coal quality.

However, the layering effect of the silo simplifies the way that coal flows through the silo. This lends itself very well to the possibility of construction a virtual coal quality silo model. Following the successful implementation of a PGNA analyzer on C2 this project will be undertaken

Figure 6. Redundant lines after the EuroSilos

After the Euro-silos the coal handling system utilizes two redundant lines. C4A and C4B are each rated at 750 tons per hour. Each one of these conveyors has the capability of supply all the demands of the plant should the other one be unavailable. Both C4A and C4B can be fed from either Euro-silo individually or from a blend of both Euro-silos. Both terminate at the secondary crusher where the coal is crushed to -1/2". This is the size of material that is eventually fed into the boilers.

Figure 7. Redundant lines after the EuroSilos

After the secondary crushers, the coal is fed onto C5A and C5B. In the future both of these conveyors will have PGNA analyzers installed on them. The goal of these two analyzers will be to verify coal blends coming out of the euro-silos and also provide input to a bunker coal quality model.

The C5A and C5B conveyors provide a nearly ideal environment for the implementation of PGNA analyzers. The cross section of material being analyzed is normally very consistent. Under typical conditions each of these belts is operated at a constant 350 tph. There is also highly accurate belt scale information available to be incorporated with the analyzers. The most advantageous characteristic of the C5 conveyors is the close proximity of a sampling system. This sampling system has been and will continue to be used as a means of obtaining data for analyzer calibration and performance verification.

Figure 8. PGNA Analyzer is located on C5A near sampler

For the trial it was determined that the best location for the PGNA analyzer would be on one of the belts feeding the boilers (C5A was chosen) and located in such a way that the existing automated mechanical sampler could be used to gather dynamic comparative data. The installed analyzer is shown above.

The Problem

Early on in plant operations a problem with coal quality arose. Whenever ash concentrations in the lignite rose to levels greater than 18% the power plant would struggle to maintain load. Periodically, significant quantities of high ash fuel would cause the power plant to trip offline altogether. These de-rates and trips would cost the power plant and the mine large sums of money in terms of lost generation and lignite sales.

The management of the power plant and the mine had two potential approaches to solving this problem. The first was a legalistic approach where lawyers would evaluate the fuel supply contract and determine which party was liable to the other. The second was to get together as a group and determine what steps each organization could reasonably take to help solve the problem. Fortunately the latter approach was chosen.

The most immediate solution to the problem involved lowering ash levels coming out of the mine to less than 18%. This would take a concentrated effort on the part of the mine, but would not involve the large capital expenditures and wholesale equipment replacements associated with increasing the plant's capacity to burn high ash fuels.

A detailed look at Red Hill's in-place coal quality reveals that none of the 6 seams have inherent ash contents greater than 18%. Even when normal mining dilutions are considered, the expected ash content seldom exceeds 18%. The greatest source of problematic fuel comes from thin seams where an abnormally large amount of interburden material has been mixed with the coal seam in the mining process. Unfortunately at Red Hills it is very easy for an operator to make these kinds of mistakes. Thin seams, night time operations, and inexperienced operators can all contribute to unnecessarily high ash fuels being delivered to the power plant.

Approaching the Problem

Unsuccessful use of a Dual-Gamma Ash Gage and Microwave Moisture Meter

One of the attempts at a technological solution to this problem involved the installation of a dual gamma ash meter and a microwave moisture meter. These were installed in April of 2002 on the main feed conveyor immediately after the lignite truck dump hopper. The intent was to monitor ash, moisture, and BTU from the office. If sudden changes in coal quality were seen, an engineer or supervisor would go to the pit to determine where the source of the problem was. By doing this, lignite loading problems could be addressed quickly and the amounts of high ash fuel could be kept to a minimum. Several things were learned by working with the dual gamma ash meter and microwave moisture meter.

- The ability to know coal quality information in real time is extremely valuable to the staff of the Red Hills Mine and Choctaw Generation. By knowing this information small problems can be addressed before they become big problems.
- Incorrect real time coal quality information is worse than no real time information at all. If users of these types of devices trust them they will forego some of the other QA/QC options available to them. They become lethargic and hang their hats entirely on the technology. This turns small problems into big problems.
- Dual gamma ash meters have a very limited application in coal mining.
  - Ash values reported are greatly influenced by the thickness of coal on the conveyor belt.
  - Every unique coal seam requires a unique calibration. Each unique coal blend would also require a unique calibration.

- Microwave moisture meter performance diminishes as moisture concentrations increase. Most vendors are leery of using them coals where moisture exceeds 30%. They are also greatly influenced by variations in bound moisture, belt loading, and seam changes.

As a result of these findings the dual gamma ash meter / microwave moisture meter project was scrapped and the equipment was removed in November of 2006. Unfortunately, despite other efforts undertaken by the power plant and the mine, the problem of high ash fuel still existed. This problem was discussed at length in a series of meetings between the power plant and the mine. Ultimately an idea arose in which the power plant and the mine would share the cost of installing and operating three analyzers. The first would be installed directly below the lignite truck dump hopper for quality control coming out of the mine. The other two would be installed on the conveyor belts leaving the silos for quality control of fuel entering the plant.

The biggest problem with this idea was that neither the power plant nor the coal mine knew of any cross belt analyzer technology that actually worked!

Successful use of PGNA

After a great deal of research the mine and the plant determined that PGNA technology may be able to provide the needed results. Several vendors of PGNA technology were then contacted. After that, several of their customers were contacted. In some cases, site visits were made. Because of the failure of the dual gamma ash meter, the power plant and the mine insisted that the agreement with successful vendor must include significant protections against unacceptable performance. In the end Sabia was the chosen vendor. The primary reasons for selecting Sabia were as follows:

- Lowest cost.
- Strong customer recommendations.
- Modular construction provide for a substantially simpler installation process involving only slight modifications to the existing conveyor frames.
- Strong pedigree. Many of Sabia's employees have been involved with PGNA from the beginning.
- Web browser based software. Analyzer data could be viewed by anyone with network access without the need for specialized viewing software.
- Experimental PGNA Moisture Meter. This is an exclusive feature of Sabia analyzer that is not available through other vendors.
- Protection against poor analyzer performance. SABIA was willing to put a unit on site on a 6 month trial lease. At the end of the trial the unit could be returned if performance was found to be unsatisfactory.

The trial unit was installed in August, 2006 with a six month trial lease. Initially the analyzer was calibrated using known static samples in the analysis region. This calibration was completed as part of the overall installation/commissioning process which took about six weeks. Although the initial calibration was crude (based on a very limited data set) the unit began almost immediately to serve as a useful trending device. The operators in the control room began watching the ash trend charts and before too long were using the data to adjust silo blending rates. By doing so they were able to avert what otherwise may have been plant de-rates or shutdown situations.

Once the unit was operating additional dynamic comparative data samples were acquired using the existing sweep-arm mechanical sampler. Given the number of seams and the large number of possible combinations thereof it took several weeks to get a data base meaningful enough to implement a robust calibration. During this interim performance optimization period the vendor worked with the customer to provide analyzer outputs to feed directly into their existing data system.

A Primer on PGNA Real-time Coal Analyzers

What is PGNA? – A Brief History of PGNA Analyzers

As a result of the pioneering work of Bob Stewart at the Bureau of Mines in the 1970's and further research under grants from the federal government and from EPRI in the 1970's and 1980's it became possible to introduce a commercially viable nuclear elemental analyzer in the mid-1980's.

The technology uses a technique known as prompt gamma neutron activation (PGNA). In this process a spontaneous fissioning nuclear source such as Californium 252 is used to bombard a sample to be analyzed with massive quantities of neutrons – several hundred thousand per second. In turn, the elemental atoms in the sample capture a large number of the incident neutrons. These atoms become unstable but quickly re-stabilize by emitting an array of gamma energies. Since each element emits a unique set of gamma energies, spectral analysis identifies which elements are in the material. As a true elemental analysis technology, it can measure on-line and in real time the quantities Silicon, Calcium Aluminum, Iron, Titanium, Magnesium, Potassium, Sodium, and Sulfur, as well as Chlorine, Nitrogen, and Hydrogen.

The first successful version of these instruments was "chute-type" analyzers that required a gravity-feed of the producer's crushed quarry materials from the top of the unit onto an exit conveyor underneath the unit. The basic sticker price for these units was as much as $1.0M. With the costs of mounting the unit and getting the cement into and out of the unit taken into consideration, the total cost of ownership often topped $1.5M. Versions are now available for around $200K with very minimal associated construction costs. Below is a timeline of the development of the technology:

The PGNA Development Timeline

> Initial sales were slow because prices were so high. Most of the initial purchases were driven by very painful penalty situations and large scale production situations with rapid return of investment.

1985 First chute-type nuclear elemental analyzer available commercially – first successful units placed in coal and cement

1986 Ad appears for PGNAA analyzer

1987 Initial units expensive – analyzer priced at $800K + $500K to install

1988 Most of the initial market penetration is in coal segment

1989 A few installations yield payback in less than 12 months

1990 Two major vendors selling PGNAA analyzers. Calibrations are site specific – in coal there is trouble with multiple seams

1991 IEA Survey shows 30 PGNAA chute-type units sold –

1992 Price/Performance Ratio makes many purchases hard to justify

1993 Slurry Analyzer Introduced in rock

> The problem of site specific calibration is solved and the technology begins to take off.

1994 First belt-type version offered for cement

1995 Lab version of PGNAA announced

1996 One main vendor dominates market with over 70% of sales

1997 Hybrid chute/belt unit introduced – vendors develop well designed factory calibration standards to allow for robust calibrations that can handle a wide variety of coal seams or variations in quarries

> Customers begin to experience dramatic benefit to operation, especially in terms of elimination of penalties and conservation of reserves and sweet coal.

1998 Units begin to gain widespread acceptance – 30 to 40 sold per year – much less nuclear source needed without sacrificing performance

1999 New vendor lowers price tag significantly for cement – prices begin to come down – three major vendors

2000 Over 100 units sold – now 4 major vendors selling services and products

2001 First belt version for coal introduced

2002 Low-cost belt version for coal introduced – units are built using the latest in computer technology – analyzers can be viewed via the internet

> Great strides have been made in accuracy and precision of the technology and prices are coming down.

2003 Version developed for mounting on conveyor – prices continue to drop

2004 High performance, easy to install versions now available for less than $250K US

2005 The technology has gained widespread acceptance although there are still occasional applications with poor results – these are usually the result of misapplication of the technology

> The technology begins to be adopted by coal burning utilities with improved up tim as a result.

2006 Nearly 300 units sold in cement, coal, and minerals industries – the market is no longer dominated by one vendor – market share spreading out

2007 and beyond – The technology will continue to shrink in overall bulk and the existence of multiple vendors will continue to put pressure on pricing to the benefit of coal handling customers. Source strength should continue to come down with no negative effect on performance.

Figure 9. PGNA development timeline

How They Work

Basic Principles

When a bulk material such as cement is bombarded with thermal neutrons, (<1 electron volt neutron energy), from a Californium 252 nuclear source, many of the neutrons are captured by elemental atoms within the cement. When this happens the atom becomes temporarily unstable. In order to re-stabilize the atom sheds a spectrum of high-energy gamma rays. The specific energies of gamma rays given off are a unique set for each of the elements within the periodic table. This principle makes it possible to create a signal to enable the on-line elemental analysis of cement possible with PGNA.

Obtaining and Processing the Signal

In order to create an electronic signal used for the determination of the weight percent of the elements of interest within the cement the unique elemental signature gamma rays resulting from the capture of neutrons by elemental atoms are detected by a scintillating crystal such as Sodium Iodide (NaI). As the gamma rays penetrate the detector they deposit their energy as high-speed electrons within the crystal. These electrons create ionization, which can be detected as UV light pulses. The light pulses are in turn detected by photo-multiplier tubes (a vacuum tube electronic component operating at a high voltage, typically 500 to 1000 VDC) and turned into electrical pulses which are immediately amplified, shaped and then converted into digital signals, and collected into a spectrum over some predetermined period of time (typically one minute) which can then be processed by a computer at very high speeds.

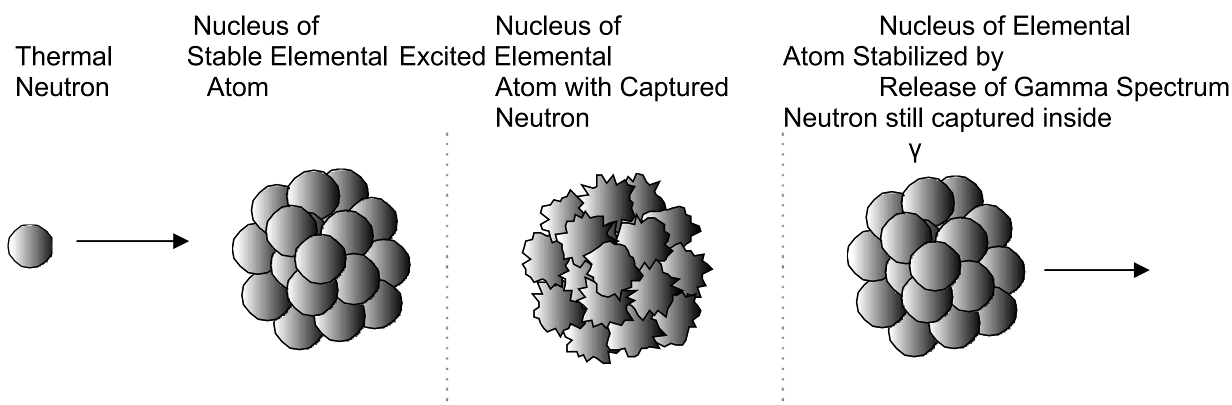

Figure 10. The Nuclear Physics of PGNA

Processing the Spectrum

The resulting gamma-ray spectrum collected over a one-minute period is actually a distribution of all the incoming gamma-ray energy levels ranging from zero to ten Mev (Million electron volts). In cement applications anywhere from five to fifteen elements of interest are represented in the spectrum. A typical spectrum is shown below which over in one minute collects several million pulses.

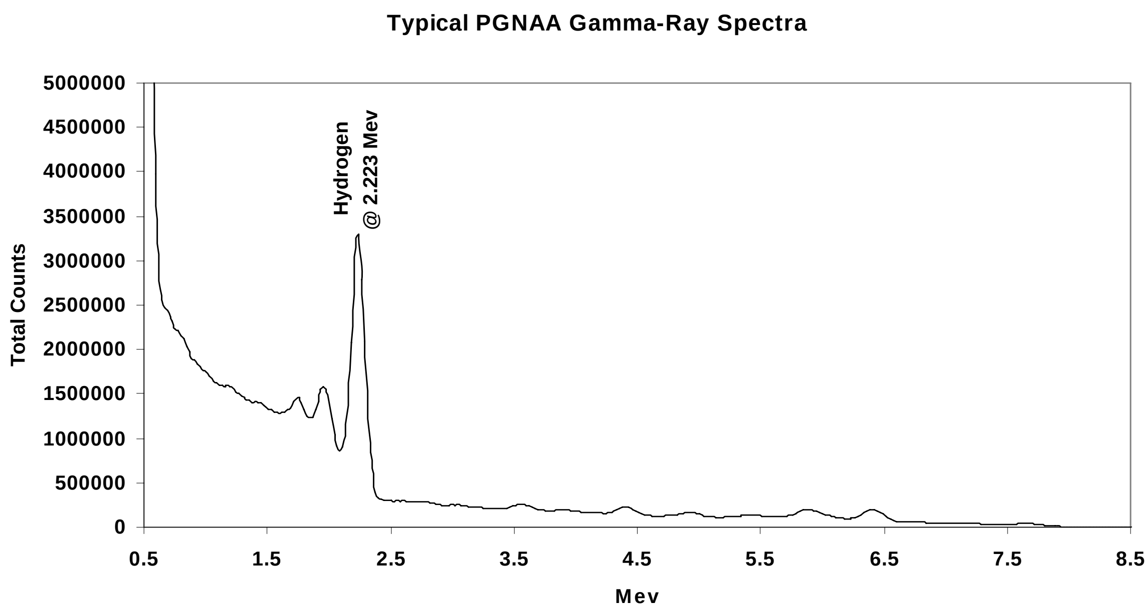

Figure 11. A Typical Gamma Ray Spectrum – High and Low Energies

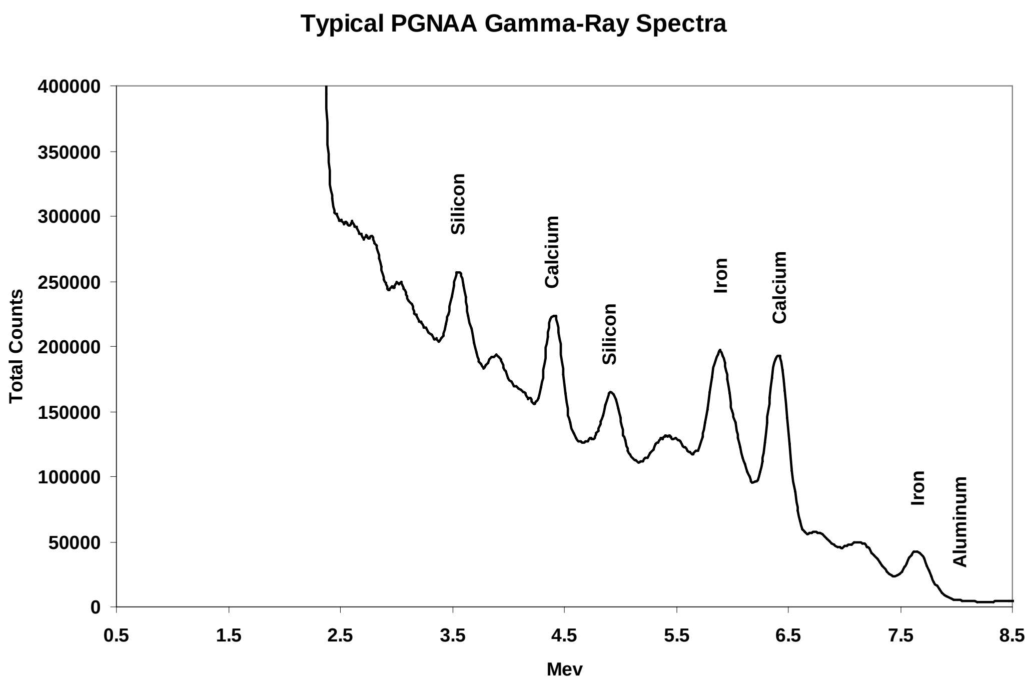

Figure 12. A Typical Gamma Ray High Energy Spectrum

Intuition says that arriving at the weight percent of each element could be accomplished with a simple evaluation of the size of each of the peaks, which is not the case. The MLR approach takes into account the entire shape of all the elemental peaks. Most commonly, vendors use a full-spectrum analysis such as Library Least Squares that utilizes the instrument response to pure elements used as a library against which the incoming spectral data can be compared on a minute-by-minute basis. Typically a multiple linear regression technique is used which solves a linear matrix equation with matrix inverse math. With the high speed and data capacity of computers available today, the time required for this mathematical treatment (de-convolution of the spectra) of the data takes only seconds and becomes transparent to the end user. Prior to presentation of the final answers to the cement producer, the results of the multiple linear- regression are normalized with respect to each other. The technology has made significant strides and now offers the marketplace impressive precisions and accuracies. **Today's analyzers calibrated in the factory with an orthogonal set of synthetic coal reference standards arrive at the site calibrated for the universe of possibilities in coal.** This means that the analyzers can be immune to changes in raw-material types.

The technology is highly accurate, with accuracies of 0.05% for sulfur and 0.50% for ash. Below is a table of sensitivities for many of the elements in the periodic table:

Table 1. Expected PGNA Sensitivity to Elements of Interest*	
Sensitivity in Weight % **	Elements
<0.01%	Cl,Sc,Ti,Ni,Cd,Hg,Sm,Gd,Dy,Ho
0.01-0.1%	S,V,Cr,Mn,Fe,Co,Cu,Rh,Ag,In,Hf,Ir,Au,Nd,Eu,Er,Yb,H
0.1-0.3%	N,Na,Al,Si,K,Ca,Ga,Se,Y,Cs,La,W,Re,Os,Pt,Pr,Tm
0.3-1.0%	Li,Be,Mg,P,Zn,As,Mo,Te,I,Ta,Pb,Ce,Tb,Lu,Th,U
1.0-3.0%	C,Ge,Br,Sr,Zr,Ru,Pd,Sb,Tl
>3.0%	Other Elements

* Note: Table taken from "On-Line Prompt Gamma Neutron Activation Analyzers, Published in the Process/Industrial Instrument and Controls Handbook, Editor-Gregory K. McMillan, Fifth Edition, McGraw Hill, 1999.
** Three sigma detection limit in 10 minutes within an elementary simple rock matrix, ≥150mm thick

Figure 13. Sensitivity of PGNA

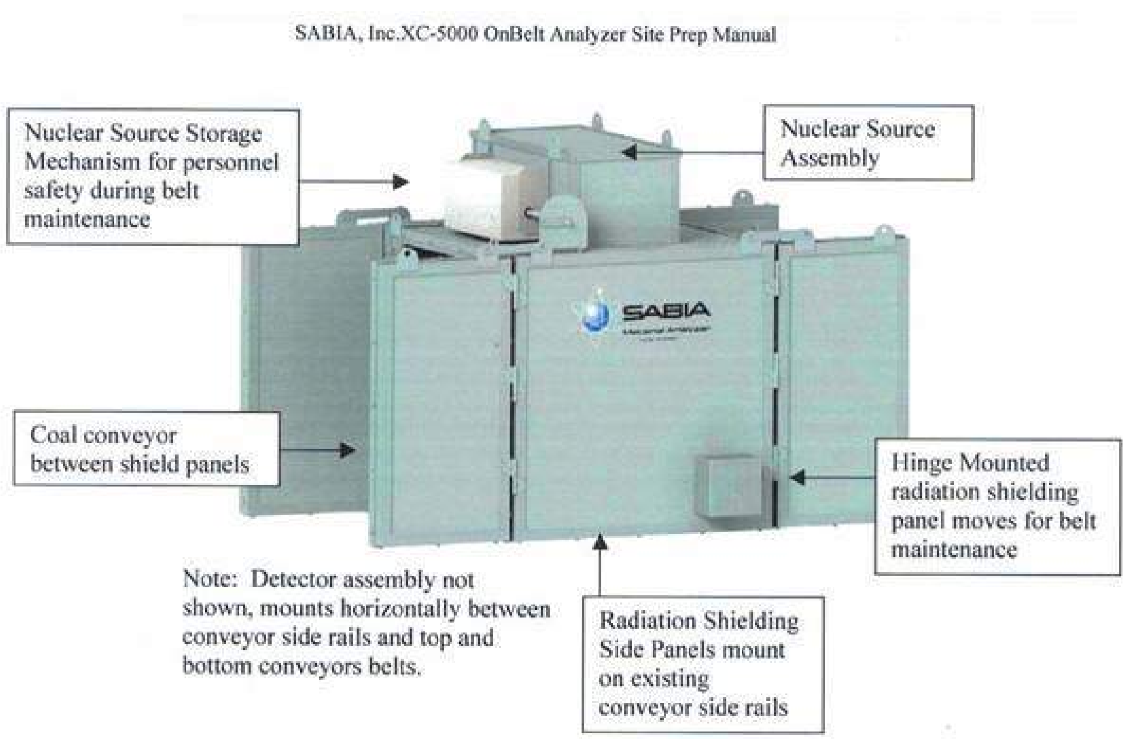

Figure 14. A version that mounts on existing conveyors

The Final Acceptance Test

In January the calibration was deemed robust enough to conduct a formal performance verification test. The test consisted of seventeen (17) blind comparisons in which the analyzer calibration had to stand on its own, without corrective calibration action.

Although already favorably impressed with the trending capability of PGNA technology, Red Hills Mine and Choctaw Generation became officially "sold" on the technology as a result of the formal acceptance test. Based on these results, the decision was made to proceed with orders for two more units. These orders were placed in March of 2007 with delivery, installation, and commissioning scheduled to take place in late spring or early summer. In addition, SABIA will continue to work with Red Hills Mine and Choctaw Generation on the related project of putting in place a silo mapping and comprehensive data base system.

Below are the results of the test:

Final Acceptance Test - Ash Comparison

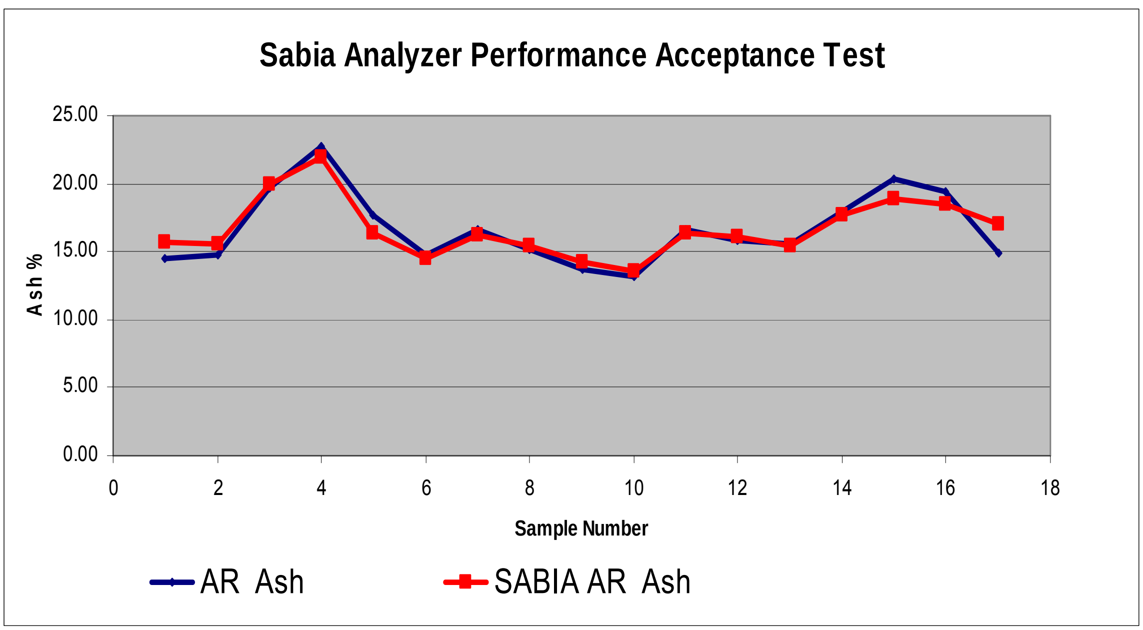

Figure 15. Ash Performance Results

Final Acceptance Test - Sulfur Comparison

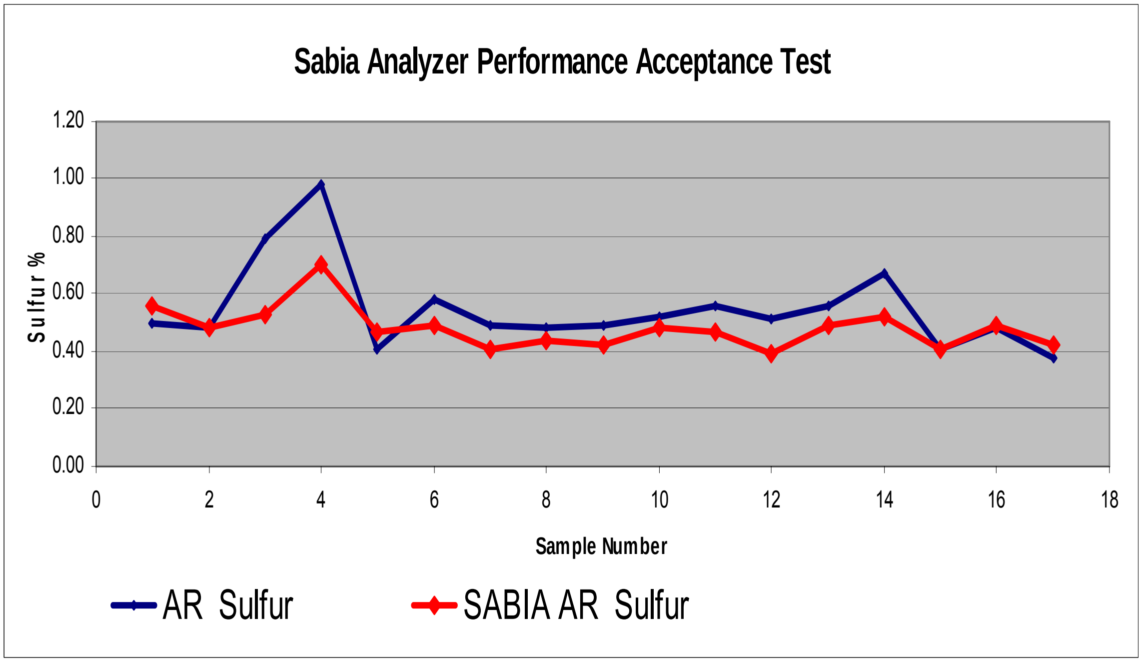

Figure 16. Sulfur Performance Results

Final Acceptance Test - Moisture Comparison

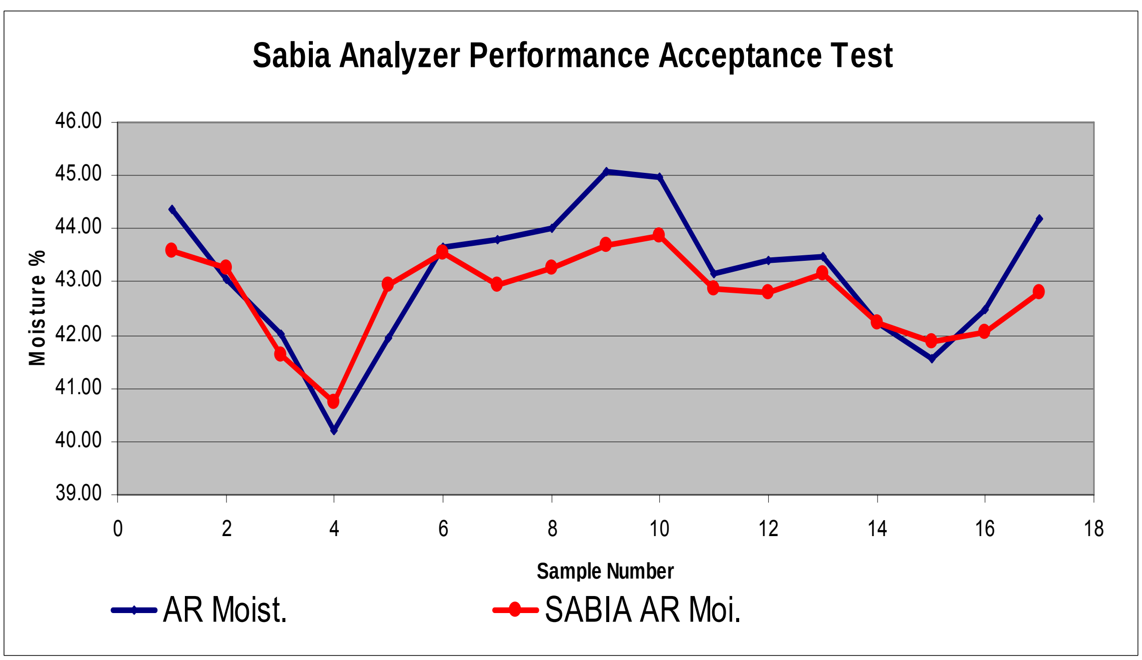

Figure 17. Moisture Performance Results

Final Acceptance Test - Moisture Comparison

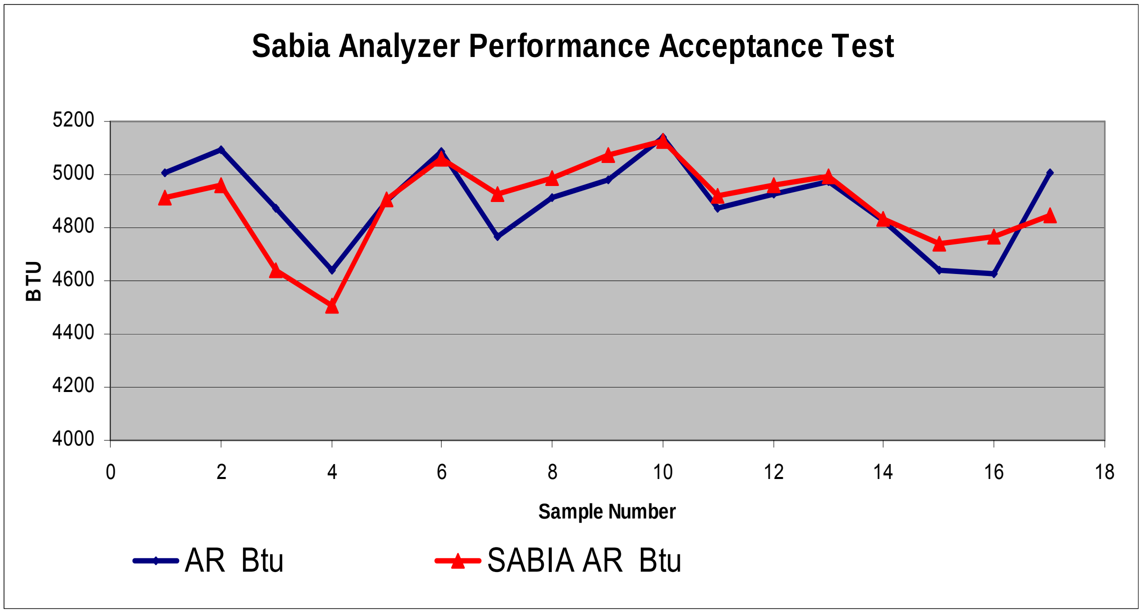

Figure 18. BTU Performance Results

Summary

As the implementation of this technology moves forward, it is anticipated that as-fired fuel quality will continue to increase and fuel variability will continue to decrease. By doing so unplanned de-rates and shutdowns can be avoided thereby increasing plant uptime. In doing so electricity sales and lignite sales are also increased, all of which reflect positively on the bottom lines of both North American Coal and Suez Energy.

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