Real time on-belt elemental analysis using PGNAA for mineral processing plant control

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ABSTRACT
This paper discusses how elemental analysis of conveyed bulk flows in real time using PGNAA (Prompt Gamma Neutron Activation Analysis) technology has resulted in significant improvements in advancing plant control in mineral processing operations.

Basis of operation of the PGNAA through belt, full stream, continuous, multi-elemental, real time analysis technology is explained. Capabilities and limitations in plant operating environments are discussed including comparison with other real time, on-line technologies through review of published information available for on-conveyor minerals applications.

Case studies demonstrate benefits provided by this technology in two operating mines. The iron ore company had prior experience with the PGNAA analyser technology, implementing an early model in a minerals application in 2003 to develop confidence in its measurement performance and usefulness of the data. A number of analysers were subsequently included throughout the new plant design for extensive measurement and control of conveyed bulk flows, from conveying after mining through to rail load-out. The copper-gold company installed an analyser to address copper ore blending issues where an on-belt system was the only viable option for the degree of control required.

Analyser suitability was evaluated through test work on site samples to determine customised multi-element precision guarantees for each application. Analyser results from normal operation are compared against laboratory analyses of multiple cross stream samples collected from conveyed flows to assess performance.

Both projects discussed were able to realise benefits previously unattainable for plant quality control, surpassing capabilities of traditional technologies which were either unsuitable for measuring conveyed flows with adequate accuracy or in real time. Equipment pay back within a few months was achieved for both sites. Through proven performance in these applications, the companies consider the technology an essential component in advanced plant control necessary in new process flow sheet designs, rather than an optimisation tool.

INTRODUCTION
Process operators rely on supply of a reasonable ore quality and consistency from the mine. Unfortunately neither the mining nor process operators have much control over the ore quality once it has been put into the crusher. Grade control typically stops once the material is designated as ore and the process plant operator needs to process it irrespective of quality.

Plant control is most effective when technologies measure process streams directly and preferably in real time. Measuring sampling streams that are not representative of the primary flow will result
in incorrect plant control decisions. Sampling coarse conveyed flows is expensive and impractical at many operations, however, this does not mean those flows cannot be measured.

Investigations to find techniques suitable for real time elemental analysis have focussed on the application of known laboratory techniques to process streams. For conveyed applications, development of neutron irradiation techniques were most promising and early studies indicated potential success for bauxite measurement (Beurton et al, 1995). Tran & Evans (2001) concluded there was no equivalent technology to PGNAA in terms of material penetration power and that the technology was eminently suitable for basic industries such as cement. Nelson and Riddle (2003) evaluated PGNAA for possible use in the phosphate industry by using a unit installed in a cement plant to test performance on phosphate samples and ultimately recommended its use for further characterisation of the mine’s various ore types to improve stockpile allocation and grade control.

Cottle (2007) discussed factory test work on a potential sinter application and Delwig et al (2011) described the successful installation in 2009 and subsequent successful performance of PGNAA for base-to-acid ratio control in sinter feed with the analyser output used to control lime addition. Geoscan (PGNAA) has been indicated by Minnett (2010) to work very well on iron ore and “improve control over what is happening in the plant” and that comfort can be provided in knowing product is on-spec. PGNAA is not yet used in the minerals sector for tariff purposes as has occurred since 2000 with Coalscan (PGNAA) in coal (Minnett, 2010).

Advantages of PGNAA include real time, full stream, accurate measurement of conveyed materials irrespective of particle size and belt speed. The system does not require regular sampling of the conveyed flow. Ore quality can be identified as soon as ore is placed on a conveyor and results are available minute by minute. Installations of the PGNAA technology for real time conveyed flow measurement in minerals processing have been limited with fewer than 50 installations worldwide to date. Interest in real time elemental data for improved plant control has increased significantly in recent years as benefits are now being realised at a number of existing operations.

PGNAA analysers require at least 30 to 50kg of material per metre of conveyor to provide reasonable measurement accuracies. This can be achieved in lower tonnage flows by reducing conveyor belt speed to increase the material load per metre of belt. PGNAA technology measurement accuracy reduces with measurement time. To overcome this, a minimum measurement time is specified that provides a balance between required accuracy and usefulness of the measurement increment in plant control decisions. While PGNAA cannot be used for particle by particle sorting, it can be used to divert increments of between perhaps 10 and 500 tonnes depending on conveyed flow. Throughput rate may be restricted by the tunnel which the conveyor passes through during analyser operation. The tunnel height limit requires that a plough or suitable deflector plate be used up-flow of the analyser to prevent impacts and damage to the analyser.

Belt scale input is required for tonnage weighted averaging of elemental results as is a measurement of moisture to enable dry weight percentage reporting. Moisture is measured either internally utilising the neutron attenuation, or more accurately through external measurement using an interfaced microwave moisture monitor. As PGNAA measures chlorine content well this technology is not being suitable for PVC conveyors, however, steel corded conveyors are acceptable. Analysers are suitable for conveyors sloping to 30 degrees and a wide range of trough angles.

PGNAA has been most commonly supplied using an appropriate radioisotope (Californium-252). A limitation of the technology is the perception of safety when plant operators are in close proximity to the unit while in operation. Analysers have been designed with heavy shielding to minimise risk
but for some designs exclusion zones are still required during operation. The weight of the system is between a few tonnes and six or seven tonnes depending on design and supplier. Neutron generators can be used instead of a radioisotope, however, there are few installations with proven reliability and life equivalent to radioisotope systems. Other variations include radioisotope size (10 – 50 micrograms), detector technology (older sodium iodide or newer bismuth germinate) and configuration (number of detectors, above or below the conveyor), slider panels to support the conveyor belt or low maintenance, non contact design. The radioisotope has a relatively short half life (2.65 years) which requires source top-up (addition of a smaller source) at not insignificant cost in addition to analyser service support. Neutron generators are safer to transport than radioisotopes but generate much higher energy neutrons when in use. The generators are less reliable as they can fail at any time (radioisotopes cannot fail) meaning a spare is usually required on site, and operating cost is much higher than that of the radioisotope operating cost equivalent.

The following sections outline the PGNAA technology operation and how this has made significant improvements to not only process control but also elemental balances, plant recovery, plant utilisation, materials handling efficiency, product quality consistency and economic viability of iron ore and copper operations. The same technology has been successfully applied in other commodities including manganese, zinc-lead and phosphate rock. Further descriptions of the range of real time analyser technologies and their applications can be found in Kurth (2007) and Kurth & Edwards (2008).

MATERIALS AND METHODOLOGY

Prompt Gamma Neutron Activation Analysis (PGNAA) is also referred to as Thermal Activation and can be used alone or in conjunction with other technologies. In the applications discussed in this paper it is mainly used alongside microwave moisture analysis to provide complementary data for calculation of multi-elemental content on a dry basis.

PGNAA is a process whereby a radioisotope, typically Californium-252, is positioned under the conveyor belt in a well shielded housing. The Cf-252 generates neutrons which are absorbed by elemental nuclei in the material on the conveyor belt. Each excited nucleus releases a gamma ray having an energy level related to the element it has been emitted from. A detector array (multiple, advanced bismuth germinate type) positioned above the conveyor belt records the received gamma rays and represents these measurements over time as a series of spectra showing peaks at energy levels representing the abundance of gamma rays measured (Figure 1).

The peaks represent the various elements present in the material and the relative abundance of each element is calculated for the time interval specified, typically in the range of two to five minutes, depending on site preference. Spectra are continuously generated. The raw data is corrected through belt load compensation algorithms, tonnage weighted using belt scale inputs, and corrected for moisture content from the nearby moisture monitor to provide dry weight percent of each element, typically reported as its common oxide form, e.g. Si as SiO₂. Moisture content is included in the results sent to the site process control system for display as trends or displayed on a proprietary SuperSCAN console.

Current analyser design incorporates a level of shielding that requires no restrictions to operator access in the vicinity of the unit during analyser operation. An “automatic source drive” that enables the Californium-252 source to be automatically positioned in a fully shielded section of the unit should the conveyor stop, the conveyor to be running empty, power to be lost to the unit, or
the system to be manually shut down. An on-board uninterruptible power supply and a local computer allow this automated shut down and start up process to be strictly controlled. The tunnel shields located either side of the main analyser body provide additional radiation protection.

Figure 1  Typical analysis spectrum

The current narrow design ensures no contact with the conveyor and material, significantly reducing maintenance costs and plant down time. This feature also improves ease of installation and reduces structural modification requirements. Conveyor sizes up to 2400mm wide can be accommodated as well as bed depths to 530mm.

One variation to PGNAA uses a pulsed neutron generator instead of Californium-252 source. This technology is described in Beurton et al (1995) in experimental work undertaken on bauxite samples. The relatively high cost of neutron generators, higher neutron energy levels and therefore more significant shielding requirements, and relatively short generator life compared to Californium-252 has resulted in PGNAA being more widely used. The PGNAA technology has been used in conveyed material analysis since the early 1990s and has continued to be the preferred technology for the coal, cement and minerals industries. Its capability to penetrate through the conveyed flow and provide accurate analyses on a minute by minute basis in conjunction with accurate through conveyor microwave moisture analyses from the separate unit (Figure 2) surpasses the capabilities of technologies using surface-only analysis techniques which are particularly unsuitable where the flow contains coarse material and where segregation of the flow occurs.
CASE STUDIES

1. IRON ORE

An early user of the PGNAA technology in minerals was an iron ore mining and processing operation in South Africa. The company used an overland conveyor to transfer crushed ore to the process plant. The quality of the ore was variable and a need to effectively monitor its composition in real time was identified to improve control of the process and allow a consistent product quality to be achieved. The analyser, an earlier version of the current model, was installed in 2003. The plant was able to respond to expected changes in ore quality before the ore arrived, and improved its performance and product quality consistency. The experience of this installation and the improvements to the design led the company to purchase a number of PGNAA analysers for its new larger plant. This plant was designed to treat a larger range of ore types and included a series of jig circuits to upgrade the various ore types. To maximise throughput of the beneficiation plant only ore requiring beneficiation was diverted to it.

The new operation utilised PGNAA analysers in a number of applications. The ore was sourced from two mines, each used an analyser to measure the ore quality fed to an overland conveyor. An analyser on the overland conveyor located prior to the beneficiation plant was used to control a diverter which allowed product quality ore to be diverter as “on grade” for minimal processing by crushing, washing and screening, then stockpiling. The run of mine ore with Fe value ≥ 65 percent, Al₂O₃ ≤ 2.5 percent and K₂O ≤ 0.3 percent was considered “on grade” subject to treatment characteristics. Only “off grade” ore was diverted to the jig plants for beneficiation. This single
diversion process realised an annual saving in treatment costs of some US$6-7 million as a large proportion of the ore flow from the mines did not require beneficiation.

Ore that did require beneficiation was able to be identified by its chemical composition as being of a particular ore type. Metallurgical test work completed in the feasibility stages of the project on each ore type had identified the upgrade potential of the iron content and target product quality. Analysers on the feed and product flows of the jigs were used to identify the ore type being received and to optimise the upgrade potential, realising the greatest value for each ore type processed. An analyser installation at this site is shown in Figure 3.

Figure 3  Elemental and moisture analyser installation in iron ore beneficiation plant

Three products are produced and each is conveyed to a separate stockpile. Product flows from the “on grade” and beneficiated “off grade” streams are conveyed to the relevant stockpile with an analyser on each conveyor measuring the quality of the ore deposited on each stockpile. An analyser located on the conveyor carrying product from the stockpiles to the rail loading facility allows the ore tonnage and quality taken from each stockpile and loaded into each train to be measured. Elemental analyses can therefore be used in conjunction with tonnage measurements to determine that status of each stockpile at any point in time.

Application of elemental analysers in this way throughout this operation has allowed staff to record the movement of ore from each mine to the processing plant in real time, optimise the plant capacity by only beneficiating “off grade” ore, maximise ore recovery by ensuring each ore type is appropriately upgraded, and improving product quality consistency, thereby maximising plant productivity. Furthermore, the plant is able to use the real time quality information and belt scale tonnage data for daily throughput and production reporting, management of stockpiles and rail
loading quality. The plant is able to undertake an elemental balance as all input and output streams are measured accurately in real time. Elements measured by each analyser include total iron, silica and alumina. In some cases manganese, potassium and titanium are measured and reported, for example in identifying particular ore types. For a more detailed explanation of the application of the analysers at this site refer Matthews & du Toit (2011). By mid-2013 this company has purchased in excess of 20 elemental analysers for use in its iron ore operations and four analysers for its manganese operations.

2. COPPER-GOLD ORE

A copper-gold operation in Laos identified the need for plant feed analysis in real time to improve control of copper metal units entering its processing plant due to a limited leach circuit capacity for dissolved copper metal. The mining operations recovered ore from several open pits where ore grade varied between <1 percent Cu and >8 percent Cu. Mine planning information was used to determine the expected average copper grade for each blast which was then hauled to the designated run of mine (ROM) stockpile and then blended with ore from other stockpiles into a crusher and conveyed to a mill. The plant was unable to utilise a slurry analyser on the milled ore as acidic solution added to the mill resulted in copper being taken into solution. Slurry analysis would not have been suitable to measure the copper in solution thereby ruling out this option.

A PGNAA analyser was purchased in late 2007 and commissioned in early 2008 on the crushed ore conveyor (Figure 4) with the main element of interest being Cu. The Cu content in the feed is controlled by adjusting the blend from the run of mine stockpiles approximately every 30 minutes as needed.

![Diagram of copper-gold plant](image)

Figure 4  Elemental analyser installation in copper-gold plant (after Arena & McTiernan 2011)

Stockpiles often contain zones of low and high grade material resulting in large variations in average feed grade. This can result in times where copper metal content exceeds the leach plant capacity. When this occurs the excess copper is not recovered while at other times a lower than expected copper metal throughput results in the leach circuit being under-utilised. In this case cost per unit tonne of copper produced increases and productivity decreases. The economics of these extremes and the likelihood of their occurrence resulted in the need for improved process control of
the plant feed quality. It was estimated by site metallurgical staff that the analyser payback would be in the order of eight weeks if the above situations could be prevented.

Through experience with the analyser the site also found benefits in knowing the sulphur and iron content of the ore as pyrite was a requirement for leach process performance. Pyritic ore was able to be added when iron and sulphur levels were below the desired target range. The PGNAA technology proved to be reliable and effective. Arena & McTiernan (2011) provide a detailed account of the plant process, analyser assessment, installation and calibration.

The suitability of an analyser for each application is assessed through a detailed site data questionnaire which indicates any potential concerns. In each of the case studies above the site provided samples equivalent to the maximum belt load for one metre of conveyor length for factory test work. The samples covered the expected compositional range to be analysed and allowed customised performance guarantees to be supplied for consideration prior to purchase commitment. As the analyser is calibrated for each application to ensure optimum performance, the risk to the purchaser is significantly reduced.

Calibration plans were developed with each site based on sampling and laboratory analysis capabilities as well as planned maintenance schedules to ensure minimal ongoing operational interruption. Initial static calibration of analysers on site was followed by approximately six monthly dynamic calibrations which in most cases were completed remotely. The remote access capability provides for minimal maintenance cost to the site and minimal presence on site by service personnel.

CONCLUSION

PGNAA analysers are most applicable where real time quality information is needed on conveyed bulk material flows. In most cases this will be as soon as the material is placed on a conveyor, typically after crushing and before milling. Analysers are also suitable for intermediate and product conveyed flows and may be suitable for use with sorters and other beneficiation technologies.

Application of PGNAA technology for on conveyor, real time, full stream, non contact, continuous, multi-element analysis has proven extremely successful at a number of mining and processing operations as detailed in this paper, as well as numerous other minerals operations. Measurement of ore and product quality has resulted in significant improvements in process control, plant utilisation, productivity, beneficiation performance, consistency in product quality, improved ore reconciliation and elemental balances.

Return on investment for the analysers have been demonstrated to be in the order of a few months. The technology has been accepted by these companies in particular and others which have experienced the benefits of real time data availability. PGNAA analysers are selected as key process control components by those companies aware of their capabilities in plant expansions, upgrades and new designs. New applications have been identified and investigations are continuing with a number of metallurgical research institutions to maximise the benefits real time, on conveyor analysis can provide to further advance process control.

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REFERENCES


