REAL TIME ON-BELT ELEMENTAL ANALYSIS FOR ADVANCED PROCESS CONTROL IN IRON ORE[1]

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Abstract

Elemental analysis of conveyed bulk flows in real time has resulted in significant improvements in advancing process control in mineral processing operations. Applications in iron ore operations are discussed with focus on demonstrable performance and measurable benefits. The iron ore company in this case study had prior experience with the analyser technology, pioneering its implementation in a minerals application some years earlier to develop confidence in its performance. 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. Analysers were fitted to existing conveyor belts. Operators were able to realise benefits previously unattainable for this advanced process control, surpassing capabilities of traditional equipment options. Basis of operation of the PGNA through belt, full stream, continuous, multi-elemental, real time analysis technology is explained. Advantages of these features are detailed in terms of operational impact including installation, calibration, maintenance, interface with plant systems and availability of data for process control. Analyser suitability was initially evaluated through test work on site samples to determine customised performance expectations for each application. Periodic analyser results are compared to expectations to validate performance. Equipment pay back of a few weeks was realised for most systems. Through proven performance in these applications, the operators consider the technology an essential component in advanced process control necessary in new plant designs, rather than an optimisation tool. Consequently, various new applications have been identified to more fully utilise the technology.

Key words: Analyser; Real time; Elemental; Process control.

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1 INTRODUCTION

Elemental analysis of conveyed bulk flows in real time is not a new idea, however, previous technologies relied upon off-line analysis of samples taken from the flow. The analyses were available for review after sample selection, preparation and laboratory analysis. The turn-around time was significant and generally not useful for real time process control.

The problem has been in developing a suitable technology that does not require sample collection from the conveyed flow but provides suitable accuracy for process control applications. Commonly used technologies were only suitable for surface analysis, for example, XRD and XRF. These technologies also require significant sample preparation and analyse a very small sample intended to represent a very large tonnage. Newer technologies such as LIBS (laser induced breakdown spectroscopy), LIF (laser induced fluorescence) and optical methods (multi-spectral or hyper-spectral scanning, etc.) are also limited to surface analysis which is not representative of the conveyed flow cross section, particularly where the flow contains coarse particles, particle segregation occurs through the vertical section of the belt load profile, or there is layering on the conveyor due to multiple flow feed points. It is rare for conveyed flows to be truly homogenised, e.g. uniformly fine particles well mixed immediately after a transfer point.

Representative sampling of process feed flows has been avoided due to high expense, inability to take large enough samples to be representative, and sample handling difficulty. Sampling frequency can be a major source of sampling error as most ores have significant quality variation over time which needs to be taken into account in the design of an appropriate sampling system.

Prompt Gamma Neutron Activation (PGNA) has been developed as an affordable real time, through-belt, multi-element, continuous and non-contact analysis technology that provides acceptable measurement accuracies irrespective of particle size and belt speed and does not have major performance limitations or maintenance requirements.

This adds a further dimension to process control as ore quality can be identified as soon as ore is placed on a conveyor and results are available within minutes. Further descriptions of the real time analyser technologies and their applications can be found in Kurth(1) and Kurth and Edwards.(2) A detailed explanation of the application of the analysers at the iron ore site featured in this paper is given in Matthews and du Toit.(3) This paper discusses the technology and its applications in iron ore using the experience of a mid-sized resources company.

2 MATERIAL AND METHODS

2.1 Technology Description

Prompt Gamma Neutron Activation Analysis (PGNA), also referred to as Thermal Activation, can be used alone or in conjunction with other technologies such as microwave moisture analysis to provide complementary data for calculation of multi-elemental content on a dry weight basis.

PGNA relies on a source of neutrons, typically from a Californium-252 radiation source of up to 50 micrograms in size, positioned under the conveyor belt in a shielded housing generating neutrons which are absorbed by elemental nuclei in the iron ore being carried on the conveyor belt through the analyser tunnel. To return to a passive state, each excited nucleus releases a gamma ray having an energy signature specific to the element from which it has been emitted. A detector array positioned above the conveyor belt records the received gamma rays and the information can be represented over time as a series of spectra (Figure 1). Optimal measurement performance is achieved using multiple advanced bismuth germinate detectors which have proven to be reliable, resilient, unaffected by vibration and shock levels previously known to affect sodium iodide detectors, and coupled with advanced DMCA (digital multi-channel analyser) electronics. These are easily calibrated and interfaced with a local control computer.

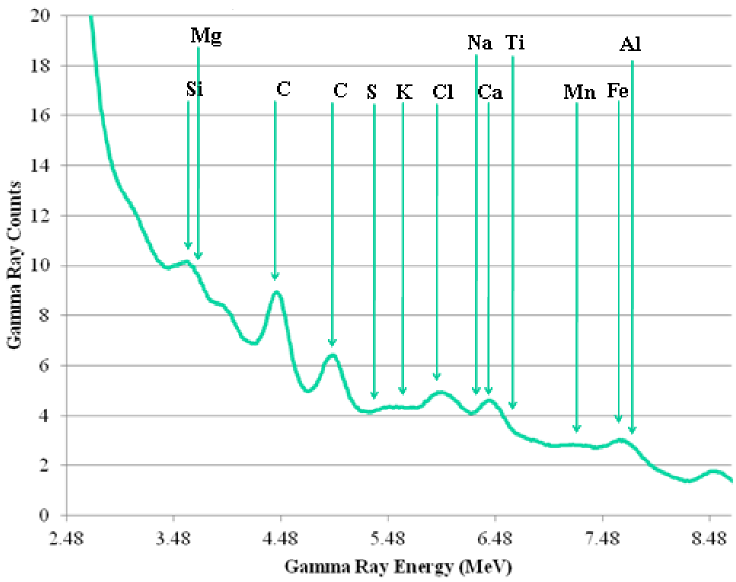


Figure 1. Typical analysis spectrum.

Spectral peaks represent the energy levels of the gamma rays recorded which indicate the presence of various elements. Proprietary software allows the relative abundance of each element to be determined for the time interval of interest as a subset of the continuously generated measurements, typically in the range of two to five minutes, depending on site preference. Raw data is corrected through belt load compensation algorithms, tonnage weighted using belt scale inputs, and corrected for moisture content from an integrated moisture monitor to provide dry weight percent of each element, typically reported as its common oxide form, e.g. Si as SiO_2. Moisture content is also reported and results are either sent to the site process control system for display through trends or ratios or can be displayed on a proprietary SuperSCAN console.

Over time further improvements have been incorporated using process operation staff feedback. As a result the current 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 2). The narrow (one metre) width allows no contact with the conveyor and material, significantly improving ease of installation and reducing maintenance costs and plant down time. Conveyor sizes from 600mm up to 2400mm wide can be accommodated as well as bed depths from 50mm up to 530mm using three different frame size options.

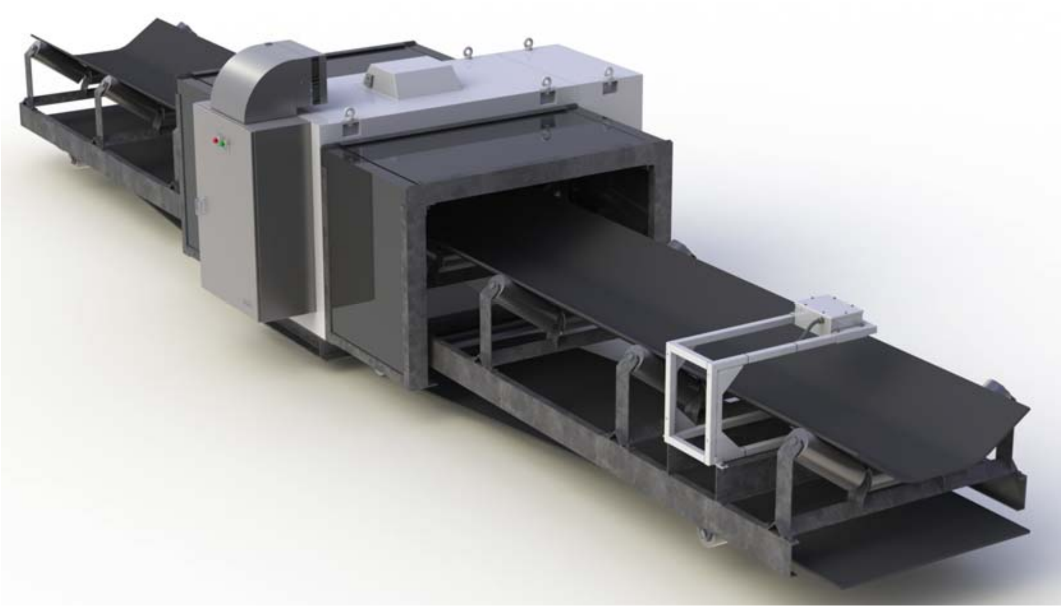


Figure 2. Elemental analyser and moisture analyser combination.

The analyser shielding is predominantly through plastic and resin filled, fabricated steel structure as well as the tunnel shields. Various proprietary components are included to maximise neutron and gamma ray absorption while minimising analyser weight and dimensions while ensuring acceptable radiation shielding performance for personnel in the vicinity of the unit during operation. No safety incidents involving radiation exposure have been reported from well over 200 installations worldwide from this supplier.

The effectiveness of the analyser used in each application is determined by a number of measures. These can include analyser performance, e.g. accuracy, availability, utilisation, operating cost, etc. and the benefit to the process, e.g. tonnes of product quality ore diverted to avoid unnecessary treatment, waste removed, increase in recovery, amount of material (shipments) out of specification, consistency of product quality, improvements to metal accounting and balances, etc. In many cases these criteria may be subjective. A major consideration to take into account when judging the performance of the technology is that the results are available in real time and therefore absolute accuracy is not the main aim. The availability of trends in the material composition over short time intervals may be more important than measurement accuracy in some applications.

The most common economic measure is the ROI (Return on Investment) as a function of time, as this is used by many companies in justification for equipment purchase.

2.2 Calibration

The analysers for the iron ore operation were configured and calibrated for composition ranges supplied by the site for each application. Performance guarantees were given for each element of interest. Conveyor belt composition, including the number and diameter of the steel cords were taken into account. Customised calibrations were supplied based on expected belt loads (measured in

kilograms per metre) for each flow. Particle size and belt speed do not affect the PGNA technology as the neutrons and gamma rays are very penetrative. The main elements of interest were total Fe, Al and Si and the K and Mn content for some applications.
Two types of calibration are used for the analyser. A factory calibration is based on static samples prepared for the expected calibration range to be analysed on site using synthetic chemical powders or samples from site. The static calibration is repeated on site to verify analyser performance during commissioning and source changes. Dynamic calibration is undertaken during normal analyser operation and is a fine tuning process to compare analyser data to a set of cross stream samples collected over a short timeframe and analysed through normal laboratory procedures. The number of samples to provide a suitable sampling precision is determined using the relevant ISO standard, where applicable. The sample results are compared to analyser data off site and any calibration adjustments are made utilising the remote access capability of the analyser which is also used for trouble-shooting and performance monitoring.

3 RESULTS

PGNA analyser performance has been assessed in a number of ways. The main criteria for a successful application vary between customers. Safety is a key aspect and no safety issues have arisen in the installation, commissioning, calibration, maintenance and operation of the PGNA analysers supplied by this company.

3.1 Calibration

As the plant was a new project, detailed data on the expected composition of each feed, intermediate and product streams intended to be measured using the analysers was unable to be provided with much certainty. Following review of the expected site iron ore composition range for a number of the conveyed flows, expected precisions as shown in Table 1 were supplied to provide an indication of expected analyser performance. Errors external to the analyser estimated from previous experience with iron ore analysis were included in the expected precision value.

Table 1. Expected analyser performance based on predicted ore composition range

Oxide or Element (% Dry Basis)	Minimum %	Maximum %	Expected Precision
Fe	50	67	0.45
SiO_2	1	30	0.85
Al_2O_3	0.5	6	0.52
MnO_2	0.03	10	0.95
TiO_2	0.05	1.2	0.20

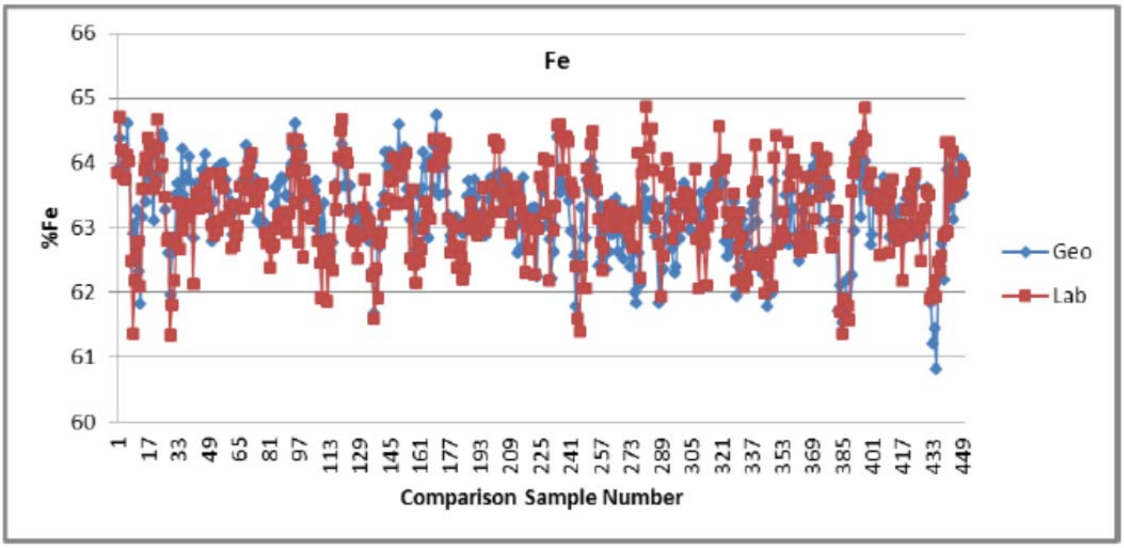
The location of cross stream samplers had been determined during plant design to ensure that relevant flows could be sampled and analysed for trace elements that the PGNA technology was not required to measure for routine process control within the operations. Review of the analyser performance in this instance involved 450 data points for comparison between the analyser and site laboratory data. Laboratory data was derived from one hour composite samples involving six primary cuts (ISO 3082:2009 recommends 25 cuts for a sampling precision of 0.25% Fe).[4] Analyser data is based on two hour tonnage weighted average results using five minute incremental results reported by the analyser.

Calculated precisions are based on the calculated standard error between the two sets of data. The standard error includes the total of the errors (sampling, sub-sampling, laboratory analysis, time synchronisation with the analyser data and the analyser measurement error). Results in Table 2 indicate that the total errors represented by the standard error are favourable when compared with expected precisions for the same elements.

Table 2. Standard error between analyser and site laboratory

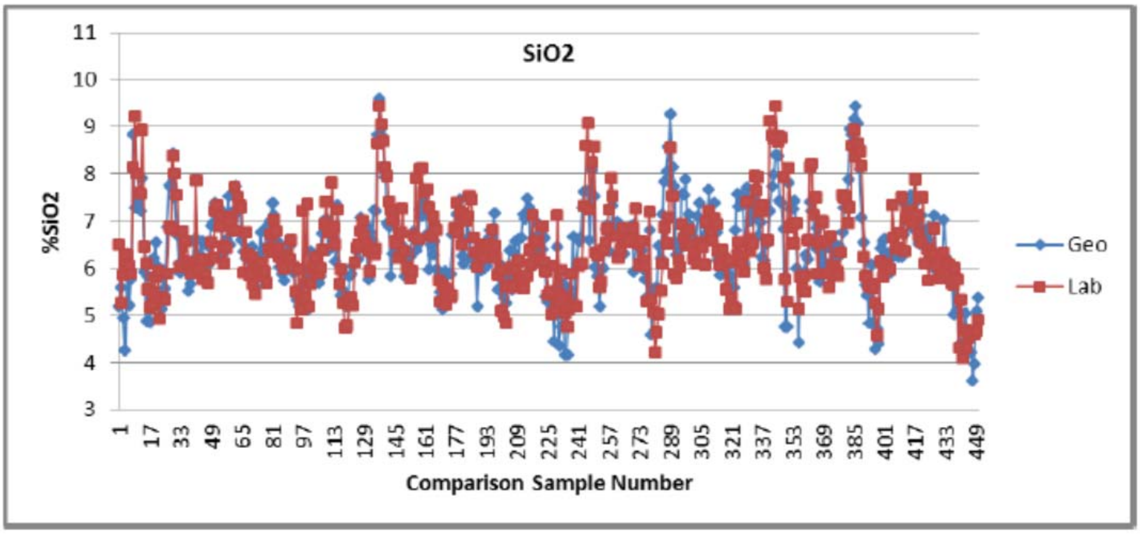
Oxide or Element (% Dry Basis)	Standard Error (total errors)
Fe	0.54
SiO_2	0.65
Al_2O_3	0.26

Figures 3 and 4 show comparisons of Fe and SiO_2 data for the iron ore between laboratory and analyser (Geoscan) which confirm the analyser measurement performance for the applications and enable the process operations staff to trust the analyses provided every few minutes. Process control decisions can be based on the results, which in some cases involve activation of a diverter gate to guide increments of conveyed flow to a different processing path.



Source: Scantech internal report

Figure 3. Fe comparison between analyser and laboratory data



Source: Scantech internal report

Figure 4. SiO2 comparison between analyser and laboratory data.

4 DISCUSSION

PGNA analysers are applicable where real time quality information is needed on conveyed bulk material flows. Decision-making based on material quality is possible once the material is placed on a conveyor, typically after crushing and before further processing. This allows the quality of the material to determine its treatment path, including potential rejection of an analysis increment (2-5 minutes duration) if it is considered uneconomic to process. Analysers are also suitable for intermediate and product conveyed flows and may be suitable for use with sorters and other beneficiation technologies.

PGNA analysers require a belt load of at least 20 to 40kg 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. Analyser software uses belt speed input to ensure the correct tonnage weighting is applied in its calculations. PGNA measures chlorine content well resulting in PGNA not being suitable for PVC conveyors, however, steel corded conveyors are acceptable. Analysers are suitable for conveyors with slopes to 30 degrees and a wide range of trough angles.

Installation of the analyser involves minor modifications to the conveyor structure and installation of a support frame onto which the analyser unit and adjacent tunnel shields are attached. The “C” shaped frame allows for installation using suitable lifting equipment in a matter of hours without the need to cut the conveyor belt. Installation is undertaken during planned plant shutdowns. A total of approximately five meters of conveyor length is required if a PGNA analyser and microwave moisture analyser are installed. All installations of the PGNA analyser are recommended to include a weather protection structure to maximise analyser life. Interfacing the analyser computer with the plant control system allows data to be reported directly to the control room for display within seconds of the analysis increment being completed.

The suitability of an analyser for each application is assessed through a detailed site data questionnaire which indicates any potential concerns. Site samples are useful in covering the expected compositional range to be analysed and allow 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 for each application 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.

The initial user of the PGNA technology in minerals was an iron ore mining and processing operation in South Africa. An overland conveyor is used to transfer crushed ore to the process plant. The variable quality of the ore indicated a need to effectively monitor its composition in real time 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 PGNA analysers for its new larger plant to be located approximately 50kms north. The new plant was designed to treat a larger range of ore types and included a series of jig circuits to upgrade various ore types. To maximise throughput of the beneficiation plant only ore requiring beneficiation was diverted to it.

The new operations used the PGNA 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 positioned 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, Al_2O_3 ≤ 2.5 percent and K_2O ≤ 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. ROI for this analyser alone was two months.

Ore that did require beneficiation was able to be identified by its chemical composition as being a particular ore type. Metallurgical test work completed in the feasibility stages of the project on each ore type had identified the upgrade potential and expected product quality, allowing analysers on the feed and product flows of the jigs to be 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 5.

Figure 5. 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. Conveyed product from the stockpiles to the rail loading facility is also analysed so that the ore tonnage and quality taken from each stockpile and loaded into each train can be measured. The elemental analyses can therefore be used in conjunction with tonnage measurements to determine the 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 weigher tonnage data for daily throughput and production reporting, management of stockpiles and rail loading quality. The plant is able to undertake an elemental balance now that 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. To mid-2013 this company has purchased in excess of 20 elemental analysers for use in its iron ore operations.

The PGNA 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 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.

5 CONCLUSIONS

Application of PGNA technology for on conveyor, real time, full stream, non contact, continuous, multi-element analysis has proven extremely successful in iron ore 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 has been demonstrated to be in the order of a few months. The technology has been accepted by this companies in particular and others which have experienced the benefits of real time data availability. PGNA 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 a number are currently under evaluation, e.g. in predictive metallurgy, where ore feed quality variations can be used to proactively manage fluctuations in critical ore composition. Scantech is working closely with a number of metallurgical research institutions to maximise the benefits real time, on conveyor analysis can provide.

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