Inside knowledge

Automated mineralogy is a valuable exploration toll, but can also be used for grade and environmental control, plant optimisation and other useful areas discussed by **John Chadwick**

Some of the known benefits of automated mineralogy (AM) include power savings. A "reduction in overall power usage during the comminution stage of processing" is possible according to Kathy Evans of JKMRC. Then there is improved metal recovery- "understanding liberation of valuable minerals from gangue" explains Norm Lotter, Xstrata Process Support.

Alan Butcher, Manager Natural Resources Strategic Marketing, FEI Australia also points out the benefits of a "reduction in leaching consumables – cost reduction in usage of leaching reagents and more efficient extraction." And in geometallurgy, "prediction of ore behaviour prior to processing, even at the exploration and discovery stage."

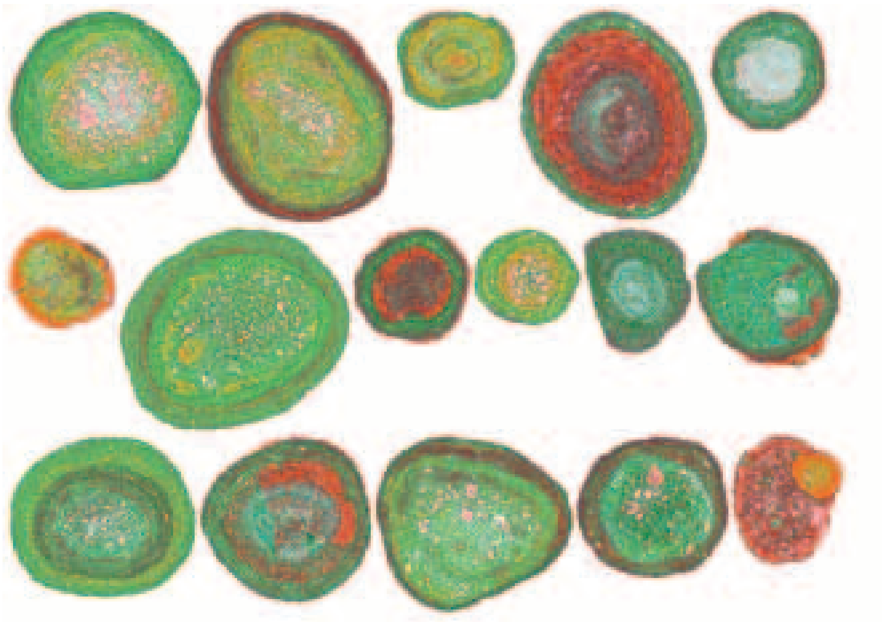
Precious metals typically occur in trace amounts; quantifying their grain size and association is a key to improving recovery. FEI explains that gold mining companies use AM solutions to quantify the proportion of recoverable gold versus refractory gold (not recoverable) in precious metal ores. This is done by analysing samples from different stages in the mining process, from *in-situ* ore, to feed ore and concentrates, and finally tailings. From this analysis, gold producers are able to understand the behaviour of metal-bearing particles, and thereby improve and optimise the metal's recovery. So, no matter what the recovery process - gravity, magnetic, flotation, roasting, bio-oxidation or pressure oxidation - gold processing plants can be monitored and audited.

A key aspect to AM is that quantitative data are generated for gold grain sizes, associations and composition, on a sample-by-sample basis. In low grade samples, customised measurement protocols allow for the rapid searching of gold grains, followed by the automated identification of all phases contained within the particle of interest, and finally the ability to relocate and manually investigate all grains and particles found. In a typical analysis, a gold producer might scan 2 million particles daily in order to gain a statistically relevant daily data set on their mine performance.

The main challenge that faces PGM producers is how to economically concentrate these very valuable minerals when they only occur in trace amounts (<1%), and as grains typically 5-15 μ in diameter, or less. Fortunately, the PGMs often co-exist with nickel and iron sulphide minerals that are more common (1-5%), have a larger grain size (10-100 μ), and are highly amenable to a process known as froth flotation. So a clear understanding of how sulphides occur within PGM ores is essential. For those PGMs that display a preference for silicates instead of a sulphides, (and in some cases this can be significant), an alternative or modified concentration method needs to be implemented.

AM enables PGM producers to understand how variations in mineralogy over time impact production samples taken from grinding circuits and the flotation cells, can be analysed by its techniques, and provide valuable insights into liberation and flotation performance as a function of: particle type, power input and reagent regime. These key input parameters allow the metallurgist to make adjustments to the concentrator so that grade and recovery of the PGM can be optimised.

On PGMs, Butcher, concludes "using automated mineralogy to better understand how these rare and very small (typically less than 10 μ) precious metal-bearing minerals occur in the ore, especially the proportion that are liberated, or locked with sulphides, or locked with silicate, as this knowledge allows for improved exploration and recovery strategies."



FEI's automated mineralogy technology helps mining companies understand ore variability in terms of mineralogy and textures. This knowledge leads to improved metallurgical processing, which in turn impacts their bottom line. This is a QEMSCAN® image of typical bauxite ore. The distinctive sub-rounded particles are the pisoliths, which form at the earth's surface as a result of breakdown of a previous rock, typically basalt igneous rock. No two pisoliths are the same – although they generally have a nucleus and core which is then surrounded by several concentric layers. The efficiency of the Bayer Process for aluminium oxide extraction is significantly reduced if impurities other than aluminium hydroxide (green) are present in the ore, such as quartz (pink), clays (brown) and iron oxides (orange) in the image

Variations in base metal ore texture such as grain size of the ore minerals, determine the grinding requirements and the extent to which liberation is achievable. These parameters can all be quantified by AM technologies. For a plant manager, liberation is a far better indicator than a chemical assay of what can be achieved in mineral processing.

Problems for metallurgists occur when run-of-mine (ROM) ore has been geologically modified, whereby the original primary sulphides are changed to secondary oxides, carbonates or sulphides. If these ore parcels pass through the plant in an unplanned way it can impact severely on metal recovery. The solution is to practice geometallurgy – the detailed study of future ore, ahead of mining, and the prediction of metallurgical response of these future ore parcels. AM solutions such as MLA and QEMSCAN® (Quantitative Evaluation of Minerals by Scanning electron microscopy) are used every day to provide inputs into these geometallurgical models and mine planning schedules.

Recent developments in grinding technology, economically reducing ore material to particle diameters measuring less than 10 μ, has allowed many polymetallic deposits to become economic mines. It is in these situations that having a detailed knowledge and understanding of the behaviour of each economic mineral by liberation class, on a size-by-size basis makes a real difference to an operations' viability. FEI says that "only Scanning Electron Microscope and EDS-based solutions, such as those provided by AM, can deliver quantification of such fine-grained materials to the process engineer.

Where chemical leaching is an alternative process to flotation, creation of ore particles with optimal surface area exposure is of greatest interest, rather than liberation, as well as a thorough knowledge of all acid-consuming minerals (carbonates, or acid-resistant minerals). AM is used routinely now by copper producers to plan, run, monitor and optimise their heap leach operations.

Butcher concludes here that the technology "allows metallurgists to investigate the flotation and leaching performance of copper-bearing minerals and phases, and thereby improve recovery from different ore types."

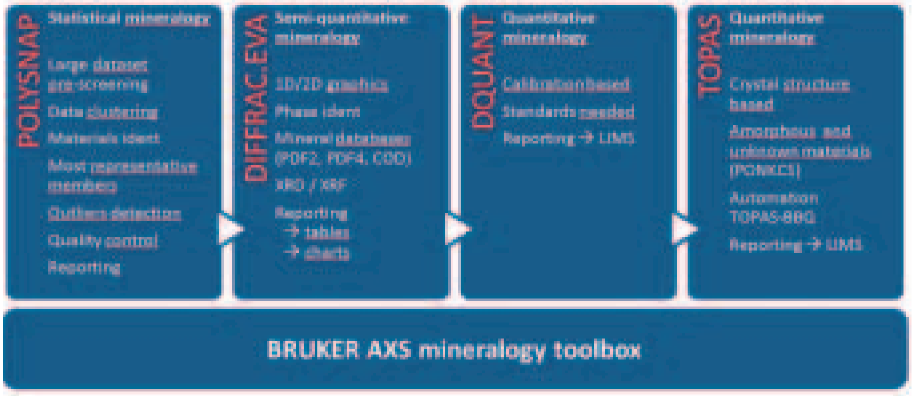
He adds that for nickel AM offers "better understanding of the role of gangue phases on the extraction of pentlandite (the main nickel sulphide mineral) which is recovered using flotation technology. Some gangue minerals, such as talc, are self-floating and contaminate the final concentrate with magnesium and silica, which can cause serious issues in the smelter."

Finally, Butcher notes "the coal industry is using automated mineralogy to characterise pulverised fuel to better predict combustion behaviour and reduce ash deposition and slag formation within power station boilers."

Some iron ore mines have areas that contain ore which is highly porous and clay-rich. Others have ore with minor impurities such as silica, alkalis, phosphorous, titanium and chromium. These can cause problems for efficient processing by gravity and magnetic methods, thereby decreasing the quality of the product, and may make an iron ore uneconomic. In these more difficult ores, AM is employed to predict, troubleshoot and improve the smelting performance. Key minerals of interest that can be identified, mapped, and quantified include hematite, magnetite, and geothite, along with apatite (P), quartz and clays (K, Na).

Bruker confirms some of the benefits already noted. "Knowledge of mineralogy adds value to all steps of the chain, starting from exploration through mine planning and operation, processing of materials, quality control, to assessment of waste products. Benefits are numerous and range from selective mining of above cutoff grade material via study of drill samples to general grade, recovery and throughput control. It helps to establish the gangue mineralogy thus allowing anticipation of the ore response to metallurgical processing conditions. It saves energy and chemicals, reduces carbon footprint and much more.

"X-ray powder diffraction (XRPD) is the most direct and efficient way to quantitatively examine minerals. XRPD applies to any solid crystalline or amorphous material with only little sample preparation needed. Milling and



pressing takes in total less than five minutes per sample; integration with major automation companies is possible. Already very little material, about 1 cm^3 of material with about 10 μ grain size, allows statistically relevant sampling.

"A major step towards complete quantitative X-ray mineralogy within minutes is the simultaneous measurement of all mineral present in the specimen using the Bruker Lynnexe detector technology. The new Bruker DIFFRAC.EVA software identifies minerals within seconds by their unique fingerprint pattern, searching several databases in parallel. XRPD distinguishes between minerals having the same or very similar chemistry. This is a major advantage over SEM based methods. The detection limit is in the sub-% or microgram range.

"The new statistical mineralogy tool POLYSNAP3 adds a major benefit to exploration work. Using cluster analysis large data-sets containing thousands of measurements of various types are grouped and the most representative members are identified for further - fully quantitative - inspection. Without needing expert knowledge materials of different origin are easily sorted and outliers detected.

"Full quantitative mineralogy is obtained from TOPAS Rietveld analysis of the XRPD data. It allows easy quantification based on the well known mineral structures. Among the latest additions is PONKCS, a method for quantifying amorphous material and minerals with no known crystal structures. The range of potential TOPAS applications covers industrial minerals, iron and steel alloying ores, precious metals, and non-ferrous metals. Bruker provides tailor made application packages for manual or automated software operation and reporting to LIMS."

The latest addition to the Bruker product family is the novel D2 PHASER with XFlash detector. It represents the first bench top system offering angle-dispersive X-ray diffraction (XRD), energy-dispersive X-ray diffraction (EDXRD) as well as simultaneous X-ray fluorescence (XRF) measurements under ambient conditions. XRF data are collected simultaneously with diffraction measurements, providing for element identification and monitoring of concentrations (K - Hf). Knowing the (partial) elemental composition of the sample greatly assists successful phase identification and quantitative analysis of unknown samples or of samples with similar diffraction patterns. Additionally, quantitative phase analysis results can be validated by comparing the calculated elemental composition with the actually measured elemental composition.

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The DIFFRAC.MEASUREMENT suite simplifies use for the operator. The multi-lingual software supports job control and gives easy access to all instrument parameters. One button operation starting with sample loading and ending with results reporting to LIMS is possible with the AXSLAB automation software. The job scheduler allows monitoring of the highest level of analytical instrument performance by regularly running reference samples. Access via inter- or intranet makes diagnostics and user support easy, even in the most remote mine locations.

All XRPD results can easily be validated. The mineralogy is fully compatible with phase analysis by minerals liberation analysis or quantitative microscopy, whereas the chemistry can be compared to any element assay method.

FEI upgrades

From FEI, QEMSCAN® is a fully automated, non-destructive, high throughput micro-analysis system that provides rapid, statistically reliable and repeatable, mineralogical, petrographic and metallurgical data, from virtually any inorganic, and some organic, materials. FEI says "it is considered a solution, rather than a tool, because it has been developed for specific industrial applications."

The MLA 650 is a high throughput automated mineral analyser used to optimise the performance of mineral processing operations. With its sophisticated backscattered electron (BSE) imaging capabilities and fast X-ray analysis, the established MLA 650 is a valuable solution for many ore characterisation, plant design and feed analysis applications. The data gathered by the MLA is therefore invaluable to metallurgists, geologists and mineral processing engineers.

FEI has recently made available two new software solutions that provide quantifiable data and its popular QEMSCAN software is now available on the Quanta™ 650 scanning electron microscope (SEM) platform. This new product has enhanced image quality and significantly faster X-ray acquisition throughput than previous QEMSCAN products.

Discussing these new software upgrades Paul Scagnetti, FEI's Industry Market Division Vice President and General Manager said: "These powerful new solutions demonstrate FEI's commitment to improving the speed, user experience, and utility of the MLA and QEMSCAN solutions. These application-specific software solutions were developed at FEI's Center of Excellence for Natural Resources in Brisbane, Australia, working closely with our customers."

With MLA v3.0 the user interface is enhanced, with flexibility in processing of particle images and extraction of quantitative mineralogical data. A completely new and integrated data management system has also been introduced, as well as simplified measurement set-up and mineral standards management protocols.

iDiscover™ v5.0 is the latest upgrade to the QEMSCAN software suite, and includes a revolutionary automated mineral identification algorithm. Customers can now directly identify more than twice as many elements, which enables more subtle discrimination of complex mineral compositions.

New Schenck Process alliance

Last year FCT-ACTech of Australia entered into a Sales Representation Agreement for its Continuous On-Stream Mineral Analyser (COSMA) with Schenck Process in multiple territories including the European Union (excluding Scandinavia), North and South America, Russia, Ukraine, Africa, India and China.

FCT has developed and patented what it describes as "the first continuous field-based on-stream mineral analyser based on innovative XRD analysis technology and is set to revolutionise the field of quality control and

Quality management in production should start as early as possible. Analysers for quality control of ROM ore must be able to identify huge material volume streams in an online and non-contact operation in order to provide instant information for control of downstream processing. LIF (LIF = laser induced fluorescence) with pulsed laser impulses can be excited in almost all minerals and rocks. The detected fluorescence intensities are very sensitive to any changes in the material composition. The signal strength due to the use of high intensity laser beams allows remarkable distances between the observed material and the optical system. For these reasons LIF spectroscopy is the preferred laser-based optical method for the assessment of poly-mineral and crystalline ROM ores and for raw material identification of multiple bulk solids in blast furnace plants in order to provide blast furnace mischarging. LIF has been proven to work in dilution control (waste and ore identification), type of ore definition (primary and oxidised ore), quantification of acid consumption of leach ores and the identification of iron ores according to their apatite-content.

The ideal installation location for LIF analysers is above continuous conveyors like belts, where they provide high statistical result accuracy with up to 100 readings per second. Thus, LIF-Online Analysers manufactured by Siebtechnik in Muelheim Germany are an ideal tool for quality management of ROM ore for dilution control and real-time information for bulk sorting, selective stockpiling, blending, heap construction and acid dosage for leaching operations or reagent dosage in typical concentrator processing. Siebtechnik says its LIF-Online Analysers "are specially designed and equipped for customer's requirements based on detailed laboratory tests with representative material samples. If required remote IP-access and service can be realised."

subsequently the optimisation of production costs."

Schenck Process says this co-operation further strengthens its position as a "global supplier of solutions for weighing, feeding, screening and automation and provides FCT with an enhanced coherent access to international markets for on-line mineral analysis, a quality control application of growing significance to end users in the metallurgical industries."

The COSMA solution designed for in-plant deployment (rather than laboratory use) uses XRD and Rietveld technologies and provides real time information for automated process control and optimisation e.g. in ore roasters and smelters or concentration plants. Many traditional mineralogical monitoring methods rely on laboratory-based rather than on-line measurements resulting in 'after-the-event' adjustments to plant control conditions.

Schenck Process says there is "an excellent strategic fit between [its] core business activities of weighing, feeding, screening, automation and bulk material handling and FCT's focus on analysis and automation technology - the result being the ability to provide a total solution package to customers for preparing and processing a correct mixture of materials to produce the required quality of product."

Blue Coast Metallurgy (BCM) has been actively using automated mineralogy data in the benchmarking and optimisation of flotation plants since it was formed in 2009.

The company explains that by extending the circuit mass balance to include specific mineral types, and even the associated degree of liberation, a far more accurate and powerful picture of how the circuit is behaving emerges. Such mineralogical balancing exercises have now been performed at several plants in the Americas, and have been used as the basis for improvement efforts. The key advantage of basing optimisation on such data is that the true plant performance can be separated from the characteristics of the ore, which is achieved by specifically focusing on the behaviour of individual mineral types and classes. It has been observed by BCM that each plant often includes an individual pattern, or fingerprint, in mineral behaviour, which when characterised results in many possibilities for plant improvement strategies and more accurate production forecasting.

In addition, BCM is working to stream line the required data, hence automated mineralogy as a tool for optimisation can be made far more cost effective, in turn broadening the reach to include small and medium sized companies and operations.

Portable XRF/XRD

Only recently have advances in XRF and XRD technology allowed for field portable analysis. With units like those from Innov-X (DELTA) and Thermo Scientific (Niton XL2 GOLDD Series and the enhanced Niton XL3t GOLDD+ Series Handheld XRF), time and money can be saved by on-site analysis of elements from phosphorus to uranium in solids, liquids, powders, cores and slurries. Exploration personnel can make immediate decisions, maximising the exploration budget. With the Innov-X Terra XRD, for example, exploration personnel can perform on-site phase identification of mining and mineral products.

Thermo Scientific's geometrically optimised large area drift detector (GOLDD) technology delivers faster measurement times and lower detection limits – as much as 10-times faster than conventional Si-PIN and up to three-times more precise than conventional smaller silicon drift detectors (SDD), the company says. This also allows light element analysis of magnesium, aluminium, silicon, phosphorus and sulphur without helium purge or vacuum assist. "When joined with advanced Thermo Scientific Niton analyser proprietary electronics, new levels of analytical capabilities are realised."

Innov-X's says its DELTA line of analysers couple ultra high resolution, large area SDD detectors with a powerful 4W tube, with application optimised anode, "delivering the

A Niton unit being used in a laboratory

super fast, amazingly precise analysis available today in a handheld XRF analyser. With dramatically reduced testing times, the DELTA allows hundreds more tests per day and a significantly higher confidence in your surface and near surface geochemical surveys. The real value arrives in the field, where the geoscientist can now use the real-time, 'Instant Geochemistry' delivered by the DELTA to postulate and start to make decisions about what the geology is doing under his/her feet and adapt the sampling and mapping program dynamically on the fly."

Or, such analysers can be used to pre-screen samples to select the best and most appropriate samples for laboratory analysis. The ability to refine a sampling program in the field, in real-time, allows simple increase of sample density and resolution, instantaneously. This leads to faster drill-hole target generation and can greatly assist the successful completion of an exploration program. During the drilling phase, handheld XRF is used to identify and quantify mineralized drill intersections. This allows optimization of drilling and laboratory analysis expenditure and other resources during field programs.

Innov-X points out that portable XRF allows for the generation of large, inexpensive geochemical data sets very quickly. Its Xplorer provides "important data management and validation framework, helping ensure the quality and integrity of your sampling program, while still in the field. Innov-X's XRF/GIS integration, the first of its kind in the industry, addresses the needs of the total project."

Field XRF data can be transferred wirelessly and spatially registered in real time using industry standard mobile GIS and the latest Trimble GPS Hardware (ArcPAD or Discover Mobile). "The result is live geochemical mapping in the field enabling visualisation, gridding, and contouring in GIS, enabling rapid, informed decision making.

"Seamless integration into powerful geochemical analysis software such as io GAS [allows] for first class data validation and QA/QC. Reduces human error related to XRF data transfer, GPS co-ordinate merging and GIS integration."

Versatile, portable XRF instruments can be used for much more than exploration, such as grade control, environmental management, metallurgy/mill ore processing and QA/QC, and heavy maintenance/oil analysis.

The following are some of the uses for portable XRF instruments, such as those of Niton or Innov-X in ore grade, process control:

- Real time grade control – underground or in open pits
- Dynamic grade delineation leads to less misallocation – I.e. less waste sent as ore or ore sent to waste
- Live chemistry determined in/on stream to help refine milling, processing and refining
- Easily check and manage stockpiles and aid in blending solutions
- Provides a crosscheck for commodity buying/selling, increasing confidence in material value
- Immediately determine the presence of S, P, As and other penalty elements
- Easily re-analyse mine tailings to determine mill performance or evaluate historical projects.

For environmental work it suggests:

- Immediately identify heavy metals in soil at low ppm levels
- Real-time metal screening in and around mining and exploration sites
- Monitor airborne metals for health impact of industrial processes to protect workers
- Meets regulatory methods for RCRA Metals & other Priority Pollutants
- Rehabilitation for sustainable development planning is faster, less expensive
- Screen waste streams and oils and community perimeters from mining processes.

Innov-X also explains such tools can be used to "keep mining machinery at peak performance with preventative maintenance. Detect wear materials in oils, plus Zn, Ba, Va. Detect other metals as evidence of contaminants in engine oils and fluids. Analyse all fluids for wear metals, additives, sulphur content and catfines (Al, Si). Prevent unexpected component failure."

Magnetic resonance

Advanced magnetic resonance techniques have been developed for mineral characterisation of iron and copper ores. The techniques quantify mineralogy by exciting specific radio frequency (RF) resonances via a rapid, non-contact method that is suited to rocks, slurries and faces, without need for sample preparation. Depending on the target mineral, the techniques can determine mineral concentration as low as 0.2 wt% within one minute or even lower concentrations over longer periods. The developments have involved engineering novel sensors that are immune to radio interference, as well as advanced frequency agile and rapidly configurable radio receivers and transmitters.

CSIRO has developed an energy dispersive (ED) XRD sensor that enables on-line mineralogical analysis of major (>few% by volume) mineral phases in flowing bulk ore streams. Traditional laboratory XRD is effectively limited to the near surface analysis of very small samples and is therefore subject to large sampling uncertainty. The CSIRO EDXRD sensor analyses tens of cm^3 of bulk samples and is suited to flowing mineral slurries or particulate solids. A prototype analyser has been constructed and has demonstrated the potential of the technology for quantitative analysis of a wide range of mineralogies.

CSIRO notes that "the current shift towards automation in mining and processing will require advanced real time measurement techniques to enable a fundamental transformation in the way mining and processing is performed. However there are few techniques that can provide a quantitative measure of bulk mineralogy across the range of measurements required, from borehole/ blasthole, mine face, conveyor or slurry measurement. Magnetic resonance and EDXRD sensors may well play a role in delivering this required transformation.

CSIRO's Minerals Down Under Flagship is developing novel, online measurement technologies that provide key analysis information at all steps from mine to metal. When integrated with industrial control systems, these technologies underpin the process optimisation needed for 'precision processing'.

Collaboration with the Brookhaven National Laboratory has led to the development of a new massively paralleled detector for fast element mapping in XRF based analyses. A prototype deployed on to the XFM beam line at the Australian Synchrotron provides the ability to map trace elements very rapidly and over centimetre scales including whole thin sections.

A novel bulk sorting concept is being developed based upon direct elemental estimation or ore grade with multistage detection and rejection of clusters of ore particles. Successful bulk ore sorting could enable operations to reduce energy consumption of conventional milling by up to 50%, and significantly reduce water consumption. The concepts currently under development are expected to enable bulk sorting of some commodities at 2,000 t/h rates.

The minerals industry has traditionally relied on XRD for mineralogical analysis and XRF for chemical composition analysis. When CSIRO researchers set out to design and build separate systems for rapid, on-stream analysis, they realised the two methods could be combined into one analyser. Dubbed XRDF, the new analyser combines the best aspects of the two analysis technologies at a near halving of the tool's cost and complexity. A new prototype is capable of measuring both mineralogy and ultra-low elemental composition directly on a process stream without the need for labour-intensive, time-consuming and potentially error-prone sampling. CSIRO says "it is ten times more sensitive than other commercial slurry analysers. Detection levels as low as 100 ppb have been demonstrated, meaning streams containing high-value metals such as gold, silver, uranium and platinum-group elements that typically occur in very low concentrations can be detected. This will present mineral processing plants with an opportunity for real-time optimisation of processing from feed to tails."

A Neutron Inelastic Scatter and Thermal Capture Analyser (NITA) has been developed for the direct on-conveyor belt analysis of materials. NITA utilises the penetrating power of neutron radiation to interrogate large volumes of material flowing on a conveyor belt. When neutrons interact with the material, gamma radiation is emitted promptly with signatures that are characteristic of the elements in the sample. NITA is a fully market-ready system.

A Low Frequency Microwave (LFM) moisture analyser has been developed and deployed. The analyser uses the propagation characteristics of microwaves to measure the moisture content of bulk ore streams carried on conveyors. Moisture content is a key parameter for bulk ore handling and conditioning. The technology was been spun out of CSIRO as Intalysis) and in the middle of 2010 was acquired by Thermo Fisher Scientific. ***IM***