Implementation of a QAQC program for in-situ grade control by Pulsed Fast and Thermal Neutron Activation methods

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Following years of development and testing, in-situ chemical assay by Pulsed Fast and Thermal Neutron Activation (PFTNA) has been implemented in mining grade control at BHP Western Australian Iron Ore as a world first. Demonstrating the technical capability and aptness of a new methodology, however, is not sufficient to ensure the sustained quality of reported assay data. The success of moving from testing stage to implementation in active mining grade control, is chiefly dependent on the robustness of ongoing quality control and quality management.

This paper shows the steps undertaken to achieve end to end monitoring of data acquired by Blasthole Assay Tools (BHAT) using PFTNA methods. The main challenge for in-situ chemical assay by the BHAT is to design a quality assurance/ quality control program (QA/QC) without a physical sample being collected, and in consequence, without the conventional separation into the focus areas sample collection, sample preparation and laboratory analysis. In this context, the BHAT combines all in one instrument, and different ways to monitor data integrity, repeatability and accuracy need to be established as outlined below.

After the validity of a BHAT calibration has been verified and a tool is in operation, data is monitored on a daily basis to check that relevant operational parameters inside the tool are working within defined acceptance limits. Measurement error in the field is monitored with repeat logs in Blastholes, and inter-instrument error by replicate logs of different BHAT units in the same Blastholes. Accuracy and instrument drift over longer periods are monitored by repeated logs in Reverse Circulation (RC) drill holes. Operational parameters, such as neutron output and spectral resolution of the instrument detector are monitored by scheduled logs in dedicated testing facilities. Also, duplicate manual sampling in Blastholes is used to compare grade populations obtained by different sampling methods in mining pits to aid grade reconciliation from mining to production. By routine application of these QA/QC steps, in conjunction with close communication of results to mining teams, the new BHAT technology has been successfully embedded in day to day mining operations.

Introduction

Chemical assay data in near real time from non-destructive methods has gained much attention in the minerals industry in recent years. In this context, the implementation of in-situ chemical assay by Pulsed Fast and Thermal Neutron Activation (PFTNA) methods[1] in mining grade control at BHP Western Australia Iron Ore (BHP WAIO) signifies a momentous change in data acquisition. At present, a small fleet of Sodern FastGrade™ 100 units, internally labelled Blasthole Assay Tools (BHAT) is mounted on downhole geophysical logging trucks and collecting assay data in Blastholes in semi-automatic operation.

A big hurdle to clear for new technology is to move from research and testing to production. And even if a new method to acquire chemical assay data passed production tests and is considered fit for implementation, the work to safeguard ongoing quality has just begun. The process of building a calibration model for BHAT instruments[2] that use PFTNA methods, and the validation steps to establish acceptable error and accuracy prior to implementation are not discussed here. Rather, this paper describes how adequate quality is sustained through continuous monitoring of control data. In this context, environmental changes, instrument drift and auxiliary operational parameters are key areas that need to be monitored.

Field controls in production logging

During production logging in grade control on mining blast patterns, the BHAT units are required to collect one repeat log per shift. The main objective here is to define and monitor repeatability of the process. Because no physical sample is taken and consequently no material is processed at a lab, the repeat logs combine field error and lab error. Major factors to consider as sources of error are the alignment of the instrument in the borehole and environmental conditions. To capture instrument drift, the two logs of the repeat are not acquired directly after one another, but at the start and end of each twelve hour shift. An example of summary results of the field error for the BHAT method in comparison to manual blastcone sampling and in-pit Reverse Circulation (RC) drilling as well as individual results by BHAT unit over a three months period at a mine site are shown in Figure 1. For simplicity, only the main elements with the biggest impact on grade control are included.

Differences between instruments are monitored by replicate logs by a second BHAT unit operating in the same mining

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area. For these, the same borehole is used as for repeat logs, which means that the borehole is logged overall four times, twice by each instrument. If required, differences between instruments are managed through planned calibration releases.

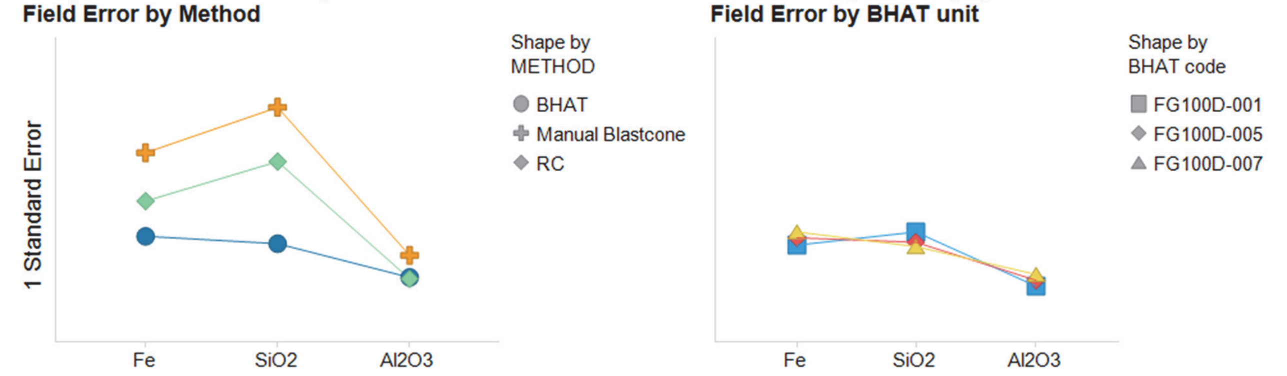

Figure 1. Summary results for different methods of assay data acquisition at a mining site (left). Note the high error for manual blastcone sampling using shovels and the lowest error for the BAHT method. The plot on the right shows field error for three BHAT units operating at the mine site, showing consistent results. Note: One Standard Error is given as the standard deviation of the absolute difference between sample pairs.

Accuracy drift monitoring and matrix changes

In general, monitoring of analytical accuracy of a laboratory is fairly straight forward by using Certified Reference Materials (CRM). For the BHAT method, however, determination of accuracy is more difficult due to the absence of a material that can be used as a true value and the absence of a controlled laboratory environment. The accuracy of a BHAT unit is assessed using a large dataset including at least 7,000 RC drill samples and 3,000 in-pit blastcone samples. After this initial validation process is completed and a BHAT unit is approved for production logging, accuracy is monitored by repeated logs in selected RC holes and by manual twin sampling in Blastholes.

Although individual sample intervals in RC drill holes show large variability and cannot be used as a true value, the repeated logs are appropriate to monitor performance over time and drift from the initial, validated state. The focus here is on monitoring relative changes from log to log, rather than the difference between original assay by XRF methods in the RC drill hole and the BHAT assay for individual sample intervals.

In addition to drift monitoring using RC drill holes, the suitability of an instrument calibration in different matrices needs to be checked in changing operational environments. In particular, moving production logging from one mining pit to another requires an assessment of accuracy in a different matrix. The main differences between mining pits are changes in mineralisation styles, moisture and porosity in the ground among others. The accuracy check is completed by manual twin sampling with a shovel of 20% of the blastcones on a mining pattern (Figure 2). The assay data acquired by manual sampling and subsequent laboratory XRF analysis is compared to the BHAT assays on a mining pattern level and assessed for likeness.

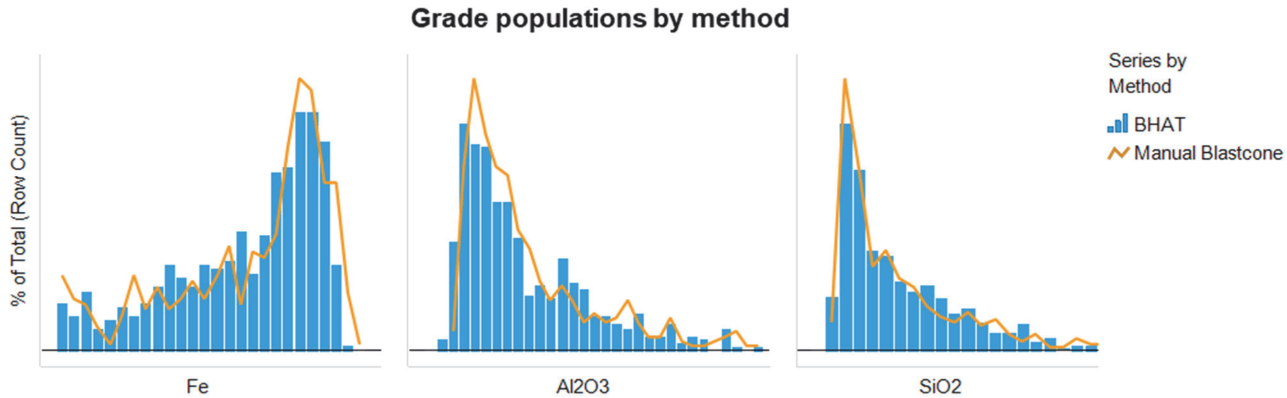

Figure 2. Illustration of grade populations of main elements on a mining blast pattern. The histograms show assay data collected by BHAT logs in Blastholes and manually twinned blastcone samples.

Spectral health

The spectral data acquired by PFTNA methods is processed into chemical assays and the assessment of error and accuracy can be used to communicate QA results for mining grade control. However, monitoring the spectral health of BHAT instruments gives the opportunity to identify potential problems at their onset before issues become apparent in the processed assays. Thus, monthly checks are completed in an artificial calibration hole. A key parameter shown as an example in Figure 3 is the spectral resolution of the instrument detector that conversely influences the ability to process spectra into assays correctly. Further, regular tests in calibration blocks monitor the output of the neutron generator which has an effect on signal strength.

Also, in day to day operations, requirements for spectral health are routinely checked for each reported data file. If predefined limits of spectral peaks are not met, the data is automatically rejected and removed from processing. Minor issues, such as unusual logging depths are flagged for review, but the data can be processed.

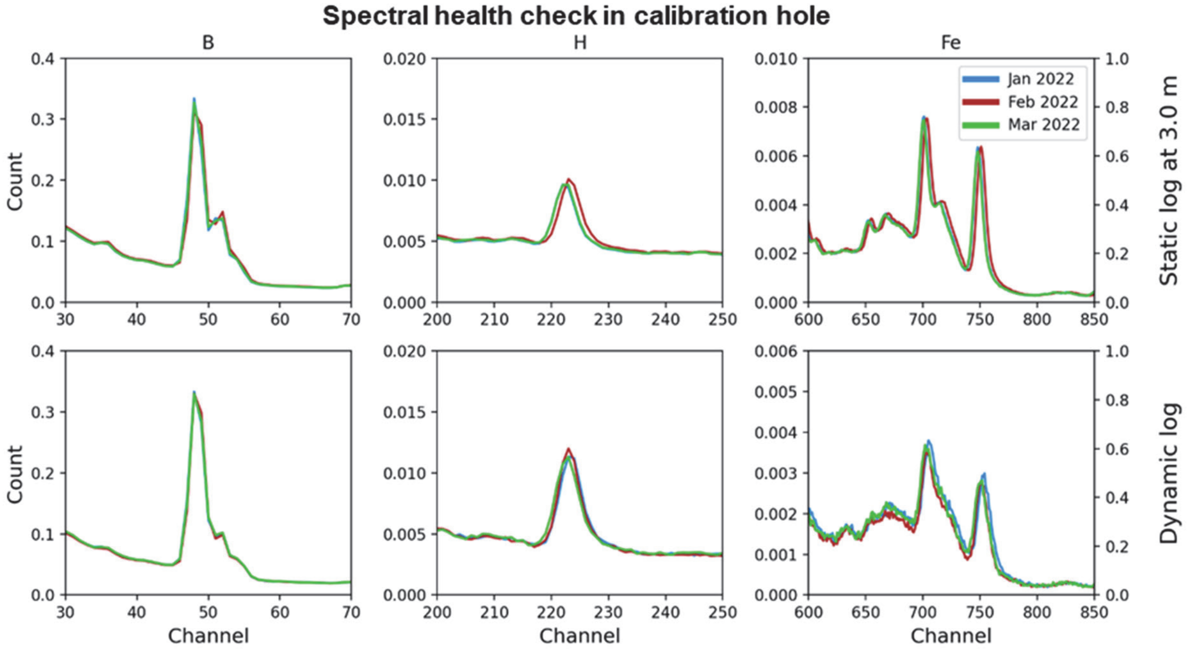

Figure 3. Monthly test logs in the artificial calibration hole at BHP WAIO facilities. For simplicity. only a selection of parameters is shown. In this example, performance over time is considered acceptable.

Operational parameters

A crucial part of safeguarding data integrity is checking the reported data formats, borehole logging locations and the performance of auxiliary systems. Incorrect logging locations that do not match planned borehole locations are flagged and raised with the operating company for validation. Also, the processing environment of the signal detector is monitored for temperature, voltage and current (Figure 4). These operational controls are important because all collected data is reported raw by the logging operators and is then processed using in-house propriety programs[2]. This is a major difference compared to laboratory assays that are generally subjected to internal checks before the data is reported to clients.

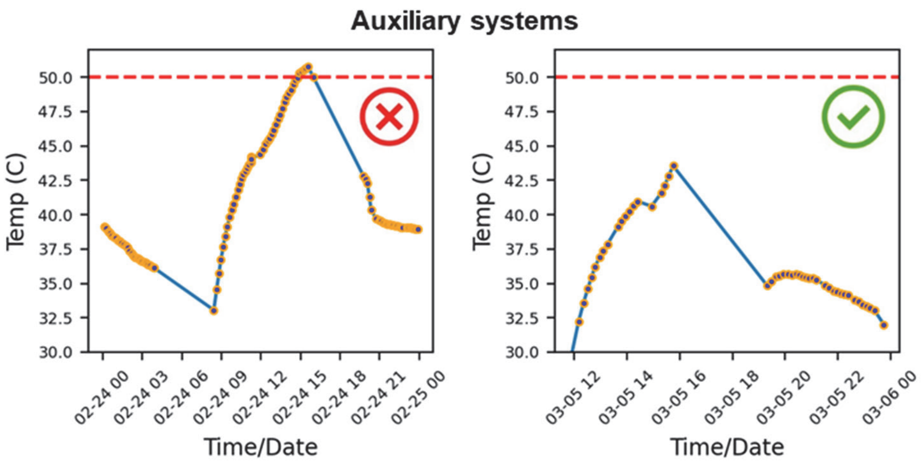

Figure 4. Temperature data from a BHAT instrument's Photo-Multiplicator Tube (PMT). Voltage and current are not included in this example. The plots show two 24 hour periods that include day and night shifts. In the example on the left, the critical temperature limit inside the instrument was exceeded.

Discussion

Implementing a QA/QC program for a new technology can be challenging because it is difficult to sufficiently define all sources of error in a test environment alone. Once the technology is embedded in full production, the focus of data monitoring can change based on newly identified gaps, and solutions need to be found quickly. An example of this is that changes in environmental conditions can have a significant impact on spectral health. Specifically, at temperatures above 50 degrees Celsius in the detector environment, the spectral resolution deteriorates. This has been observed in pairs of repeat logs where the first log is collected at the start of a shift in the cool early morning hours and the second log on a hot afternoon. Countermeasures are now put in place to prevent overheating in a pro-active manner. This highlights the importance of continuous monitoring of auxiliary system parameters and regular revision of control parameters based on learnings in the field. Compliance with operation procedures is monitored on a weekly basis and potential issues are raised with field teams. What is important here is good communication between client and contracted operating company to clarify changing requirements and improve on previous results.

Local differences in environmental conditions between mining blast patterns are also identified as contributors to misalignment of the applied calibration. In particular, moisture and porosity in the formation can influence the captured BHAT spectra and thus the conversion to chemical assays. Also, areas with an unusually high number of ground cavities or otherwise widened borehole diameter, have an effect on spectral results and give rise to problems with signal processing. Manual twin sampling on new mining patterns provides a practical check to see if results have changed compared to the approved calibration model. It needs to be considered though that due to the very high variability of this sampling method, individual sample pairings have limited meaning. However, at a mining pattern level, the grade populations observed in manual blastcone sampling are expected to largely overlap with grades reported by the BHAT. Thus, the mining pattern population analysis can identify these problems should they arise.

Validation of instrument accuracy while in production logging is challenging due to the absence of CRM. Carefully sampled and assayed Diamond drill holes, otherwise regarded as the best case for sampling, are not suitable because the measurement footprint of the instrument extends up to 40 cm distance into the wall rock beyond the borehole and homogeneity of the material cannot be assumed. However, based on previous test work using RC Bulk Sampling and direct comparison of the BHAT method in Diamond and RC drill holes in cross-reference tests, the RC method is considered overall unbiased. Consequently, if the variability of RC samples is taken into account, the mean grades of the reference method (RC) and the test method (BHAT) in relevant element concentrations can be used to establish acceptable accuracy.

A key factor in promoting confidence in chemical assay data by the BHAT method instead of physical sampling methods and laboratory XRF assays, is regular reporting of QA/QC results and good communication with stakeholders. In this way, opportunities to improve can be identified and actions put in place to further build on the consistent quality of results.

Conclusions

Grade control by PFTNA methods in mining operations at BHP WAIO is now successfully implemented. This has been supported by establishing a QA/QC program that monitors field error, instrument performance over time and operational parameters. Importantly, changes in the logging environment and the rock matrix are also considered. It is emphasized that the work on developing and refining QAQC routines is not finished. Rather, operational procedures and control requirements are regularly updated based on new findings and the growing experience with this new technology.

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