CHRYSOS CORPORATION
Assays at the speed of light

Technical Note TN-130

Chrysos PhotonAssay™ Data Outputs

Executive Summary

This technical note provides a detailed overview of the standard outputs produced by the PhotonAssay™ system. These outputs include the assay grade, measurement precision, flags, jar weight and jar fill. The assay grade is typically the most important result for the end user, but the other outputs can provide important insights into the measurement quality and nature of the samples being analysed. This document highlights how these additional outputs can be used.

Related Documents

Performance Note PN-000 Chrysos PhotonAssay™ Services Summary

Performance Note PN-001 Chrysos PhotonAssay™ Gold Services

Performance Note PN-002 Chrysos PhotonAssay™ Concurrent Gold and Silver Services

Performance Note PN-003 Chrysos PhotonAssay™ Copper Services

Technical Note TN-106 Chrysos PhotonAssay™ for Gold Measurement and Impact of Interfering Elements

Contents

Executive Summary i
Contents ii
1. Introduction 1
2. Assay Grade 1
3. Instrument Precision 1
4. Jar weight and fill 2
5. Flags 3

1. Introduction

PhotonAssay™ is an assay technique for the accurate, quantitative determination of gold, silver and copper grades in mineral ore samples. It uses high-energy X-rays from an electronic source to activate atoms of the target metal and then detects gamma-rays of specific energies emitted as these atoms relax back to an unexcited state. By detecting and counting these characteristic gamma-rays, the masses of the targeted metals present can be determined, and their concentrations calculated.

Each element is measured using a specific PhotonAssay™ service. Gold can be measured using the standard 2-cycle gold service (PAAU02). Silver can be measured concurrently with gold using either the 1-cycle silver-optimised service (PAAGAU01) or the 2-cycle gold-optimised service (PAAUAG02). Copper is measured using the standard 1-cycle copper service (PACU01). The reader is referred to the relevant Performance Notes for each of these assay services for more information.

Each PhotonAssay™ service provides a standard set of outputs for each measured jar, including assay grade, instrument precision, flags, jar weight and jar fill. This note describes each of the standard data output produced by the Chrysos PhotonAssay™ system.

2. Assay Grade

The 2-cycle services (PAAU02 and PAAUAG02) involve two 15 second irradiation cycles through the unit. As a PhotonAssay™ jar enters the detector station during each cycle, the top and bottom detectors will count and record the gamma rays released as the excited element nuclei relax back to the ground state. An average of the four total recorded values collected during the two cycles will be calculated, and a final assay grade will be reported for each jar.

One-cycle services (PAAGAU01 and PACU01) involve one 40 second irradiation cycle, so the final assay grade is the average of two discrete measurements (top and bottom detector values).

The measurement of gold is optimised using 15 second cycles, while the measurement of silver and copper is optimised using a 40 second cycle. When conducting concurrent gold and silver measurements, the service will either be optimised for gold (PAAUAG02) or silver (PAAGAU01).

Each PhotonAssay™ jar measured will report an assay grade for each measured element, in units of ppm for gold, silver and copper.

3. Instrument Precision

Instrument precision or repeatability describes the variation in grade that would be observed for repeated measurements of a uniform sample. The PhotonAssay™ precision for a given sample depends on the grade, the presence of background elements such as uranium, thorium and barium, and sample heterogeneity.

For all but the most extremely heterogeneous samples, PhotonAssay™ precision is dominated by the statistical errors associated with counting individual gamma-rays emitted by the sample. The analysis software used to calculate the assay grade also calculates the expected instrument precision for each reported grade value using conventional error propagation techniques. The calculated precision is also used to determine the detection limit (DL) for each element in the sample.

4. Jar weight and fill

When samples are loaded into the PhotonAssay™ unit, they are weighed and their volume is measured using a specially developed camera system that images material inside the jars, allowing the density to be determined. The density of the sample is an important parameter used to determine the X-ray and gamma-ray absorption factors that correct for attenuation of the incident X-ray beam and the outgoing gold gamma-rays inside the sample matrix. The sample mass is also used in the final calculation step to convert the contained gold, silver or copper mass to metal concentrations. The jar weight and fill-level are parameters available to the end user. Jar fill is often tracked for QAQC purposes as a low jar fill decreases the instrument precision (Table 1) and increases the sampling error.

Table 1 Impact of fill factor on instrument performance for different gold grades using the PAAU02 service.

Fill factor	Gold Grade			
	0.3 ppm	1 ppm	3 ppm	10 ppm
50 %	9.0 %	5.5 %	3.2 %	2.1%
60 %	8.2 %	5.0 %	3.0 %	2.0 %
70 %	7.6 %	4.7 %	2.8 %	< 2 %
80 %	7.2 %	4.4 %	2.7 %	< 2 %
90 %	6.8 %	4.2 %	2.6 %	< 2 %
100 %	6.5 %	4.0 %	2.5 %	< 2 %

5. Flags

Statuses and Flags are reported alongside the assay grade and precision to provide additional information about the nature of the sample being assayed. These flags also help to provide insight into the analytical process occurring within the unit. Table 2 documents these flags and provides guidance around the recommended operator responses. Status types are ordered approximately according to their frequency of occurrence.

Most status flags are raised based on the same spectral data used for grade analysis and are subject to the same statistical fluctuations. Samples that lie near a threshold condition can be expected to intermittently report the status flag on repeated measurements.

Table 2: Chrysos PhotonAssay™ measurement flags and definitions.

Status	Definition	Description	Actions	Applicable Services
BDL	Below detection limit	The assay grade is below the 2-sigma detection limit. The detection limit is calculated per jar and is twice the Instrument Precision (Au_Err). The detection limit for each PhotonAssay™ jar is reported in the grade column. The detection limit (2σ) on materials with minimal concentrations of background elements are: • PAAU02 – Au: 0.01 ppm • PAAUAG02 – Au: 0.017 ppm, Ag: 3.7 ppm • PAAGAU01 – Au: 0.03 ppm, Ag: 1.5 ppm • PACU01 – Cu: 30 ppm	No further action required by operator. Additional action would be to analyse the sample using more measurement cycles. Services with more cycles have a lower detection limit due to the improved counting statistical precision.	All
OVR	Over measurement range	The grade is above the upper limit of the measurement range for that service. Gold • PAAU02 – Upper limit 350 ppm • PAAU02H – Upper limit 3,500 ppm • PAAU02HH – Upper limit 10,000 ppm Silver • PAAGAU01 - Upper limit 5,000 ppm	The operator is required to re-analyse the sample with the “high range service”, applicable for gold and copper. If OVR flag is still reported on the “high range service”, the operator is required to re-analyse the sample with the “HH service”, applicable for gold only.	All

Status	Definition	Description	Actions	Applicable Services
		• PAAUAG02 – Upper limit 5,000 ppm Copper • PACU01 – Upper limit 4 wt% • PACU01H – Upper limit 30 wt%		
HB	High background	Reported for jars with elevated background due to the presence of other elements in the jar. For these jars the instrument precision and detection limit will be worse compared to clean samples of a similar grade. For gold and silver, the key background elements are U, Th and Ba.	No further action required by operator.	Au, Ag
HET	Heterogeneous sample	Reported when the PhotonAssay™ system detects that the element of interest is not uniformly distributed throughout the sample volume. This is inferred by comparing the signals measured by the top and bottom detectors. If the estimated elemental grades from these independent readings are not statistically consistent, 'HET' is reported. The uneven distribution of the element throughout the sample volume does not significantly impact the quality of the assay grade except in the case of extreme heterogeneity (eg single gold nugget in the jar), however, the reported precision may underestimate the measurement repeatability. For gold measurements, this status typically indicates that the sample contains coarse gold. Results are still meaningful when the HET flag is present.	No further action required by operator. Additional action would be to analyse additional PhotonAssay™ jars from the original supplied bulk sample to reduce sampling error.	All

<table>
<tr><th>Status</th><th>Definition</th><th>Description</th><th>Actions</th><th>Applicable Services</th></tr>
<tr><td>IEC</td><td>Interfering element, corrected</td><td>The presence of an interfering element has been detected and a correction has been made to enable assayed element grades to be reported.

The table below shows the approximate concentration ranges for each interfering element in a 300 g jar when the correction is applied. Above this range an IE status will be reported.

<table><tr><th>Element</th><th>IEC concentration (ppm)</th></tr><tr><td colspan="2">Gold and Silver</td></tr><tr><td>Bromine</td><td>7.5 - 75</td></tr><tr><td>Erbium</td><td>75 - 750</td></tr><tr><td colspan="2">Silver</td></tr><tr><td>Gold</td><td>25 - 350</td></tr><tr><td colspan="2">Copper</td></tr><tr><td>Germanium</td><td>15 - 150</td></tr></table></td><td>No further action required by operator.

The reported result has been corrected.</td><td>All</td></tr>
<tr><td>IE</td><td>Interfering element</td><td>The sample contains concentrations of interfering elements greater than those listed in the IEC table in the previous entry. This prevents a result being reported for that jar.

Gold and silver
Bromine and Erbium
Silver
Gold
Copper
Germanium</td><td>Operator may re-run the jar on the “high service” as this may produce a useable grade, depending on the concentration of the interfering element.

IE flags can on rare occasions be triggered by incorrect weight and fill measurements. The operator can manually confirm the mass and fill values and update them if required. If updated, the sample can then be rerun.</td><td>All</td></tr>
</table>

Status	Definition	Description	Actions	Applicable Services
ERR	System Error	An issue has been identified with the system operation, for example, a jar cycle mismatch caused by the automation system cycling a jar incorrectly.	Operator is required to re-run the jars in another batch.	All
NS	Not suitable	An issue has been identified with the sample preventing analysis. For example, the sample has extremely high concentrations of elements such as U, Th or Ba leading to detector saturation.	Operator may rerun the jar on the appropriate high-grade service to assess the cause of the problem.	All
IS	Insufficient sample	The material fill is less than 50% of the total jar volume, as determined either by the fillometer or manually flagged by operator.	Operator is required to fill the jar and ensure volume is > 50%; the recommended minimum fill for optimal precision is 85%.	All
LS	Lost sample	Flagged by operator.	Operator is required to re-fill jar with reserve material from original split, if available.	All
XS	Excess sample	There is more than 1 kg of material in the jar.	Operator is required to split and re-jar the sample.	All
LT	Low Transmission	The sample is sufficiently dense or contains substantial concentrations of high-Z materials, such that the gamma rays do not penetrate through the sample. These instances are very uncommon for gold or copper, but can occur for analysis of silver in samples containing more than 5 wt% lead.	Contact Chrysos for potential next steps.	All