The Use of Measurement Uncertainty in an Operating Mine

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Mine Activities Using Test Results and Associated Measurement Uncertainties

- Exploration to expand reserves.
- Breaking up deposit material (drilling and blasting rocks).
- Deciding which is ore and which waste.
- Separating mineral(s) of interest from gangue (the concentration process).
- Shipping product to the customer.

Decision Points in the Process

- Does the blasted material go to the mill or to waste?
- How much metal was fed from mine to mill?
- Are the mineral separations efficient?
- Does the mass of metal in the concentrate plus that in the tailings match what was in the mill feed?
- What is the value of the metal in the product being sold?

WHAT ROLE DOES MEASUREMENT UNCERTAINTY PLAY?

A Look at Mine Statistics

- The Cu grade of the ore is 1.17 %
- The cut-off grade (is it waste or does it go to the mill?) depends on metal prices.
- An example is a cut-off grade of 0.10 % Cu. Anything less than 0.10% goes to waste at a low Cu price but not necessarily at a higher one.

What Goes to Waste?

- With Cu at $3.00/lb (LME price in June 2010) $6.62 worth of Cu is in 1000 kg of 0.10 %Cu rock.
- With Cu at $4.25/lb (LME price April 30, 2011) $9.37 worth of Cu is in 1000 kg of rock running 0.10 %Cu.
- If it costs $7.00 to treat 1000 kg of rock through the mill, then 0.10 % Cu material would go to waste in the first case and to the mill in the second.

But What of Measurement Uncertainty?

- If the expanded (k=2) uncertainty of the sampling and analysis of Cu in the rock at 0.1 %Cu is 0.01%, the amount of Cu could vary from 0.9kg to 1.1 kg in 1000 kg.
- The value of Cu in the rock at $3.00/ lb ranges from $5.94 to $7.26 per 1000 kg.
- Given these numbers the decision would probably be to send the rock to waste.

But What of Measurement Uncertainty?

- If the expanded uncertainty of the sampling and analysis of Cu in the rock at 0.1 %Cu is 0.02%, the Cu in 1000 kg would range from 0.8 kg Cu to 1.2 kg Cu.
- The value of Cu in the rock at $3.00/ lb ranges from $5.28 to $7.92 per 1000 kg.
- Given these numbers, the decision of waste vs. mill is more difficult to make.
- The larger uncertainty makes the decision less clear cut.

But What of Measurement Uncertainty?

- At $4.25/lb, the value of Cu in 1000 kg of rock with an expanded uncertainty of 0.01% would lie in the range $8.42 to $10.20.
- At $4.25/lb, the value of Cu in 1000 kg of rock with an expanded uncertainty of 0.02% would lie in the range $7.48 to $11.22.
- Thus with the higher Cu value there is no doubt about the rock going to the mill.

Decisions, Decisions, Decisions

- The mine operators will have to establish decision rules to deal with situations such as the $5.28 - $7.92 range of Cu values seen in an earlier slide.
- The fact that they know the measurement uncertainty gives them a basis for making an informed decision.
- The measurement uncertainty must include sampling and sub-sampling variances.

Mine/Mill Mass Balance

- The Mine/Mill Mass Balance is a regular calculation done to monitor a mining operation in an attempt to balance the amount of metal going into a mill against the amount coming out of the mill in the concentrate plus that in the mill tails.

Mine/Mill Mass Balance

- This calculation involves three sampling events and three analyses:
  - Mill feed
  - Mill tails
  - Concentrate
- This means three different measurement uncertainties.

Mine/Mill Mass Balance

- The three uncertainties each involve variability due to:
  - Sampling and sub-sampling (lack of homogeneity)
  - Analysis
- Sampling the mill feed is usually the largest source of variability because the material sampled is of large particle size. Sampling in the mill can be significant.

Mine/Mill Mass Balance

Range % Cu	Standard Deviation Calculated from Duplicate Analyses in the Lab	Standard Deviation Calculated from Duplicate Mill Feed Samples
>0.01 to 0.10	0.00335 % Cu (relative)	0.00729 % Cu (relative)
>0.10 to 1.0	0.0594 % Cu (relative)	0.136 % Cu (relative)
> 1.0 to 10	0.0495 % Cu (relative)	0.351 % Cu (relative)
25% (Concentrate)	0.479 % Cu (relative)	N.A.

Mine/Mill Mass Balance

- Assume the average grade of the 90,000 metric tons (90,000,000 kg) of ore going into the mill daily is 1.1 % Cu.
- The standard deviation of the sampling of that mill feed is 0.136 % Cu (previous slide).
- The uncertainty of how much Cu enters the mill daily when estimated using 2 SD is 990,000 ± 2700 kg Cu.
- This is over $20,000 worth of Cu at $4.00/lb

Mine/Mill Mass Balance

- If the Cu recovery is 95%, 5% goes to tailings and 95% goes to concentrates.
- This means 940,500 kg of the Cu reports to the concentrate and 49500 kg to the tailings.
- The concentration in the tailings would be 100 x 49,500/89,000,000 = 0.0556% Cu.
- The SD at this concentration is 0.00335 % Cu as shown in the previous table.

Mine/Mill Mass Balance

Ore to mill kg	Cu in Concentrate kg	Cu in tails kg
90,000,000 (95% recovery of 1.1% Cu in ore)	940,500 kg	49,500
Standard Deviation of Cu results absolute	0.00489 kg Cu	0.00335 kg Cu
MU of Cu results (2 SD's)	9200 kg	332 kg

Mine/Mill Mass Balance

- The reconciliation of how much Cu went into the mill and how much came out is subject to large uncertainties.

1. ± 2700 kg Cu going into the mill.
2. ±9200 kg Cu in the concentrate.
3. ±332 kg Cu in the mill tailings.

- These large uncertainties mean that getting a perfect reconciliation of the mass balance is difficult.

Measurement Uncertainty for Cu Concentrate Shipment Analyses

- The analysis of concentrate shipments is critical because of the large dollar values of such shipments.
- For this reason it is important to get a reliable estimate of measurement uncertainty in that analysis.

Measurement Uncertainty for Cu Concentrate Shipment Analyses

- An important first step is to identify the likely sources of variability contributing to the uncertainty.
- There are three sources:

1. Uncertainty in the value quoted for the certified reference material (V_{RM}).
2. Uncertainty in the analysis ($V_{b)}$
3. Uncertainty in sampling during the loading (V_{samp}).

Measurement Uncertainty for Cu Concentrate Shipment Analyses

- $V_T = V_{RM} + V_b + V_{samp}$ = 0.00320 + 0.000625 +0.00437 = 0.00879
- $SD_T = (0.00879)^{1/2}$ = 0.0905 % Cu
- Expanded uncertainty U = 0.18 % Cu
- The reported result in the 25 % Cu concentration range is xx.xx +/- 0.18 % Cu at a 95 % level of confidence.

Concentrate Shipment Protocol

- The seller samples the concentrate as it is loaded onto the ship.
- The seller analyses the samples using rigorous quality control.
- The buyer pays 90% of the value of the shipment as determined by the seller's sampling and analyses.
- The buyer samples the shipment as it is unloaded and analyses the samples.

Concentrate Shipment Protocol

- The two sets of results are compared and if they are within the pre-agreed splitting limits the final 10 % of the payment is made based on the average of the two sets of results.
- If they are not in agreement each party sends a cut of their sample to an agreed umpire laboratory.
- Final payment is made based on the umpire laboratory results and the “losing” lab pays.

Concentrate Shipment Protocol

ANALYTE	TOTAL SAMPLES	TOTAL SAMPLES (Without Umpire)	TOTAL SAMPLES TO UMPIRE	TOTAL SAMPLES TO UMPIRE (Won)	TOTAL SAMPLES TO UMPIRE (Lost)
Silver	2963	2770	193	87	106
	100%	*93.49%*	*6.51%*	*45.08%*	*54.92%*
Cooper	1862	1667	195	94	101
	100%	*89.53%*	*10.47%*	*48.21%*	*51.79%*
Zinc	986	930	56	35	21
	100%	*94.32%*	*5.68%*	*62.50%*	*37.50%*

Measurement Uncertainty in Shipment Settlements

- The splitting limits are set based on the negotiated agreement between the parties.
- Common splitting limits are set in the range 0.25 to 0.50% Cu by mutual agreement.
- The expanded MU of 0.18 % Cu quoted earlier for concentrate shipments allows the seller to be confident of being able to detect a bias of this magnitude.

What Role Does Measurement Uncertainty Play?

- Measurement uncertainty permits more knowledgeable decisions to be made:
  - Does material go to waste or to the mill?
  - Is the concentration process efficient?
  - Is the mass balance reconciliation acceptable?
- Is the sampling and analysis of concentration shipments good enough to detect a bias for negotiated splitting limit purposes?