New Sampling Technologies for Ore Grade Control, Metallurgical Accounting, and Laboratory Preparation

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ABSTRACT

The optimisation of a mining operation requires precise ore grade control, metallurgical accounting, and laboratory sampling protocols, which are implemented by using accurate and flawless sampling systems. Good sampling practices, and sampling technologies in these fields have been historically poor and too many existing sampling systems available on the market are flawed in many ways. This is mainly the result of a poor understanding of the Sampling Theory, and the natural result of international standards on sampling that fail to present the Sampling Theory in a logical way, that still promote non-probabilistic sampling, and that fail to address the important details that make a correct sampling system. Many standards barely mention the Sampling Theory in appendices when it should be clearly the main body of a reliable standard on sampling. As a result, many standards show only little expertise in the Sampling Theory. Conventional statistics should only be a scientific tool for the Sampling Theory to reach its height, which has always been well understood by its creators. Conventional statistics can indeed be addressed in appendices of standards in sampling, but not the other way around. Until the Sampling Theory is recognised as the main body of a standard on sampling, incorrect sampling technologies will plague the market, and make it impossible for mining operations to optimise their mining and metallurgical processes. This paper makes a short list of correct new sampling technologies that have been created with respect to the principles taught in the Sampling Theory. Perhaps, they are not the panacea, nevertheless they show a new awareness trend from some manufacturers willing to make an effort in manufacturing correct sampling systems: It is a refreshing development in the excessively conservative world of mining, nevertheless much more work needs to be done. Also, suggestions are presented to create better international standards on sampling, which would provide a stronger incentive for manufacturers to build correct sampling systems, and for engineering firms to install only sampling systems that respect the rules of sampling correctness listed in the Sampling Theory.

INTRODUCTION

The strength of the Sampling Theory: Dividing a complex problem into a sum of simpler problems

The Sampling Theory (Gy, 1992, 1979, 1983; Pitard, 1993) divides the total variance S^2_{Total} of the uncertainty of a sampling-weighing-analytical effort into the following basic components:

$$S^2_{Total} = [S^2_{QE1} + S^2_{QE2} + S^2_{QE3}] + [S^2_{AE}] + [S^2_{DE} + S^2_{EE} + S^2_{PE} + S^2_{WE}] + [S^2_{WG}]$$

where:
$[S^2_{QE1} + S^2_{QE2} + S^2_{QE3}]$ is the variance of a sampling protocol domain in which:
S^2_{QE1} is the variance of a small-scale source of uncertainty, mainly the result of an *in situ* Nugget Effect *NE*, Fundamental Errors *FE*, and Grouping and Segregation Errors *GE*. These sources of uncertainty are minimised when optimising a sampling protocol, respectively optimising *in situ* sample volume prior to drilling, sample and subsample masses, and number of random increments and homogenisation.
S^2_{QE2} is the resulting variance of the uncertainty in a composite sample in which each increment is capable of representing the large-scale variability between pre-selected strata.
S^2_{QE3} is the resulting variance of the uncertainty in a composite sample in which the role of each increment in representing the large-scale variability between pre-selected strata has been affected by the presence of a cyclic phenomenon.

$[S^2_{AE}]$ is the variance of the analytical measurement . The analytical variance S^2_{AE} should not include the last sampling errors introduced by the collection of the final analytical subsample.

$[S^2_{DE} + S^2_{EE} + S^2_{PE} + S^2_{WE}]$ is the variance of the domain of the practical implementation of a sampling protocol. It is the domain of emphasis for this paper, in which:
S^2_{DE} is the variance of the increment Delimitation Error. This error is the result of a sample increment boundary that does not give all the material of a lot to be sampled the same chance of being selected. It is a dangerous bias generator.
S^2_{EE} is the variance of the increment Extraction Error. This error is the result of a sampling tool that is selective on the kind of fragments it takes. It is another dangerous bias generator.
S^2_{PE} is the variance of the increment Preparation Error. When the sample increment is submitted to crushing, grinding, pulverizing, homogenising, screening, filtering, drying, transporting, and packaging, its physical or chemical integrity can be greatly altered, resulting in a Preparation Error, which itself can therefore be the sum of many errors. It is another dangerous bias generator.
S^2_{WE} is the variance of the increment Weighting Error. The mass of each sample increment should be proportional to the mass of the lot stratum it is supposed to represent.

$[S^2_{WG}]$ is the variance of the weighing domain. The variance S^2_{WG} of the error introduced by weightometers and scales is a critically important part of the estimation circuit for conciliation assessments between mine forecasts and plant reality.

Clarification about the use of the word 'error' versus 'uncertainty'

'Error': *the difference between an observed or calculated value and a true value; variation in measurements, calculations, or observations of a quantity due to mistakes or to uncontrollable factors.*
It is the word 'mistake' that bothers statisticians.
'Uncertainty': *lack of sureness about someone or something; something that is not known beyond doubt; something not constant.*
Historically, statisticians prefer the word 'uncertainty' because there is no implication of a 'mistake' that could have been prevented. The word 'uncertainty' implies there is no responsibility.
In 1967, Gy (1967) stated: 'With the exception of homogeneous materials, which only exist in theory, the sampling of particulate materials is always an aleatory operation. There is always an uncertainty, regardless of how small it is, between the true, unknown content a_L of the lot L and the true, unknown content a_S of the sample S. A vocabulary difficulty needs to

be mentioned: Tradition has established the word 'error' as common practice, though it implies a mistake that could have been prevented, while statisticians prefer the word 'uncertainty' which implies no responsibility. However, in practice, as demonstrated in the Sampling Theory, there are both sampling 'errors', and sampling 'uncertainties'. Sampling 'errors' can easily be preventively minimised, while sampling 'uncertainty' for a given sampling protocol is inevitable. For the sake of simplicity, because the word 'uncertainty' is not strong enough, the word 'error' has been selected as current use in the Sampling Theory, making it very clear it does not necessarily imply a sense of culpability.'

Gy's choice was especially justified for Delimitation Error, Extraction Error, and Preparation Error, because indeed, the magnitude of these errors is dictated by the ignorance, unwillingness, or negligence of operators, managers, and manufacturers to make these errors negligible by following rules listed in the Sampling Theory. For these errors, the word 'uncertainty' would be inappropriate.

Gy's definitions

a_L is the true unknown content of the lot L.
a_S is the true unknown content of the sample S: it is an *estimator* of a_L.
Any difference $a_L - a_S$ is a sampling error.
SE is defined as the relative, dimensionless Selection Error: $SE = \frac{a_L - a_S}{a_L}$

It is understood that the estimator a_S has a probability distribution. Therefore, several appreciation factors should characterise the Selection Error *SE*:

1. the mean $m[SE]$ of the variable *SE* which is a measure of the selection accuracy,
2. the variance $\sigma^2[SE]$ of the Selection Error, a measure of the selection reproducibility, or precision,
3. the mean square $r^2[SE]$ which is a measure of the sample representativeness, with: $r^2[SE] = m^2[SE] + \sigma^2[SE]$

In practice, a_S is replaced by a laboratory *estimate Est.a_S*, therefore the convention is taken in the Sampling Theory to replace $\sigma^2[SE]$ with its estimate $s^2[SE]$.

MODERNISING STANDARDS ON SAMPLING FOR THE MINING AND CHEMICAL INDUSTRIES

Statisticians and Standards Committees often consider sampling (ie *SE*) as an inseparable entity and only the total sampling error is considered, the one that exists between a_L and *Est.a_S*. This is exactly where the disagreement between the Sampling Theory, and existing statistical circles and Standards Committees takes place. As long as this state of affairs persists, several consequences are inevitable:

1. As long as Delimitation Error *DE*, Extraction Error *EE*, and Preparation Error *PE*, the existence and definition of which are absolutely unambiguous, are not assessed separately, causes and cures for $m[SE] \neq 0$ and for large, unacceptable $r^2[SE]$, are inaccessible.

2. As long as *in situ* Nugget Effect *NE*, Fundamental Error *FE* and Grouping and Segregation Error *GE*, the existence and definition of which are absolutely unambiguous, are not assessed separately in the selection of a sampling protocol, causes and cures for a large, unacceptable value of $s^2[SE]$, are inaccessible.
3. As long as Long Range Quality Fluctuation Error QE_2 and Periodic Quality Fluctuation Error QE_3, and Weighting Error *WE*, the existence and definition of which are absolutely unambiguous, are not assessed separately in the selection of a sampling protocol and the selection of a sampling mode, causes for a large, unacceptable $s^2[SE]$ and $r^2[SE]$, and for $m[SE] \neq 0$, are inaccessible. For example, recommendations in standards to minimise $s^2[SE]$ using a larger number n of increments, in grab or manual interleaved sampling, forget that the number of increments has nothing to do with $m[SE] \neq 0$ and probably little to do with a large, unacceptable value for $r^2[SE]$.

Recommendations to modernise sampling standards

1. Eliminate statistical jargon in the first 75 per cent of standards on sampling, replacing it by a clear set of definitions, and appropriate references to reliable textbooks of fundamentals of statistics, which are, by all means, extremely relevant and inescapable. Or, at least, place this information at the end of the standards, in annexes.
2. Eliminate any form of non-probabilistic sampling practice (eg grab sampling, manual sampling, sampling of stockpiles, etc…) from standards, since they necessarily result in $m[SE] \neq 0$ and large, unacceptable values for $s^2[SE]$ and $r^2[SE]$, leading to confusion and chaos.
3. Replace the chapter on Mechanical Sampling in existing standards, loaded with ambiguous definitions of problems, by the thorough, far more complete, scientific approach to sampling correctness (ie *DE, EE*, *PE, WE* and sampling modes that may greatly affect QE_3).
4. Clearly make a difference between random and non-random differences between increments or samples x_i and x_j a certain distance, time, or tons apart. Assuming sampling and analysis (ie Analytical Error *AE*) are preventively accurate (ie $m[DE] + m[EE] + m[PE] + m[WE] + m[QE_3] + m[AE] = negligible$), the total error estimation $s^2[SE]$ in a heterogeneous material stream can be summarised as in the following formula, well known in geostatistics:

$$s^2[SE] = \underbrace{\frac{s^2_{Random}}{n}}_{\text{This is the Central Limit Theorem applying only to the random variability.}} + \frac{1}{n^2} \underbrace{\sum_{i=1}^{n} \sum_{j=1}^{n} \operatorname{cov}\left[x_i, x_j\right]}_{\text{Non-random variability}}$$

But, as long as the standard is not clearly preventive for *DE, EE, PE, WE,* QE_3, and *AE,* individually*,* guidelines given for selecting an effective sampling protocol (ie *NE*, *FE, GE,* QE_2) may remain ineffective.

5. Finally, something has been missing for too long in the Sampling Theory, which is the important issue of Data Quality Objectives (*DQO*): When a sample is assayed, what is it exactly that someone intends to do, or prove, with the results? Answers to that question have an enormous impact on how a representative enough (ie $r^2[SE]$), and economical enough (ie precise enough, $s^2[SE]$) sample can be defined.

Recommended definitions of 'error' and 'uncertainty'

1. If a selected sampling/analytical protocol leads to a large, unacceptable uncertainty $s^2[SE]$, it in turn can become a large, unacceptable error if nothing is done to select a better protocol. Indeed, with the Sampling Theory and good laboratory practice we have all the necessary tools to find causes of problems for *NE*, *FE, GE, QE2,* and *AE* and prevent mistakes incompatible with *DQO*.
2. If the selected sampling equipment is not correct, or a non-probabilistic sampling device is used during the implementation of the protocol, leading to unacceptable uncertainty $r^2[SE]$ and $m[SE] \neq 0$, they in turn can result in a large, unacceptable error if nothing is done to select correct sampling equipment. Indeed, with the Sampling Theory, we have all the necessary tools to find causes of problems for *DE, EE, PE* and *WE* and prevent mistakes incompatible with *DQO*.
3. If the selected sampling mode (ie random, stratified random, random systematic, or strictly systematic) is not correct and leads to unacceptable uncertainties $s^2[SE]$ and $r^2[SE]$ and $m[SE] \neq 0$, they in turn can result in a large, unacceptable error if a better sampling selection mode is not implemented. Indeed, with the Sampling Theory we have all the necessary tools to find causes of problems for QE_3 and prevent mistakes incompatible with *DQO*.

PRACTICES TO ELIMINATE IN CURRENT SAMPLING STANDARDS

Non-probabilistic sampling methods, nearly always affected by delimitation and extraction problems should be eliminated from sampling standards. This should include any form of manual sampling, grab sampling, deterministic sampling, authoritative sampling, sampling in bags or drums, sampling in trucks or railroad cars. As long as such sampling methods are recommended in a standard, the standard should be rejected because it indirectly promotes malpractice. A statement such as 'Mechanical sampling from moving streams is the preferred method' is not a strong enough statement to discourage people to practice non-probabilistic sampling: Instead, the standard must clearly say that non-probabilistic sampling methods are not acceptable.

The length of this paper being restricted, only a few well-focused examples may help to set the course for developing better sampling standards.

SAMPLING CORRECTNESS FOR EXPLORATION

Difficulties during drilling exploration can be summarised in very short statements: Clearly define the objective; is it a race to collect as many samples as possible, or is it a careful collection of representative samples? It cannot be both.

Problems associated with diamond core drilling

Diamond drilling, because of the very small diameter involved, is very sensitive to the *in situ* Nugget Effect, therefore, the larger the diameter the better. The minimisation of the Delimitation Error is usually a matter of good surveying. The minimisation of the Extraction Error is far more difficult; the key is good recovery. A 90 per cent recovery can lead to the loss of 50 per cent of the gold in some types of gold mineralisation (Pitard, 2002).

Problems associated with Reverse Circulation drilling

Problems with Reverse Circulation drilling are many. Down-hole contamination can lead to a Preparation Error leading to a preparation bias, finally resulting in the wrong location of the mineralisation. Selective separation of coarse and fine particles, partial liberation of some minerals, combined with poor or excessive recoveries can lead to devastating extraction biases.

The 'Plucking Effect': An extraction bias

As part of the Extraction Error, there is a subtle phenomenon that takes place during exploration drilling. It can be called the 'Plucking Effect', and it has escaped the attention of many geologists around the world.

Definition of the 'Plucking Effect'

In the following discussion, it is assumed the mineral of interest is Chalcopyrite. Chalcopyrite in a given geological unit may occur as disseminated little grains, as tiny veinlets, or as more massive veins. As a diamond drilling machine cuts its way through the mineralised area, a slick core sample showing full account of the Chalcopyrite grains, veinlets and larger veins is expected: Reality is different. Figure 1 shows the 'Plucking Effect' generated by a diamond core drilling machine, while Figure 2 shows what happens with a reverse circulation drilling machine and with a blasthole drilling machine as well.

- As a result of the inward effect illustrated in Figure 1, diamond core drilling always shows slightly lower chalcopyrite contents than it should, and there is nothing anyone can do about it. Sawing the core with a diamond saw or a core splitter just aggravates the problem.
- As a result of the outward effect illustrated in Figure 2, reverse circulation drilling (ie RC) or blasthole drilling always shows slightly higher chalcopyrite contents than it should, and there is nothing anyone can do about it.

Attempt to quantify the 'Plucking Effect'

Let's define a few terms, with some of them further illustrated in Figure 3:

a_L the true chalcopyrite content of the rock (per cent),
a_C the chalcopyrite content from diamond core drilling (per cent),
a_R the chalcopyrite content from RC drilling (per cent),
d_L the average observed size of the chalcopyrite grains, or veinlets thickness (cm),
R_C the radius of the diamond core (cm),

R_{Ceff} the effective radius of the diamond core (cm),
R_R the radius of the RC hole (cm),
R_{Reff} the effective radius of the RC hole (cm),
H the length of the drilling intercept (cm),
D the density of the rock (g/cc).

For all practical purposes, we assume that $R_{Ceff} = R_C - 0.5d_L$ and $R_{\mathrm{Re}\,ff} = R_R + 0.5d_L$

The true weight W_C of the sample given by core drilling is:

$$W_C = Dh\pi R_C^2$$

The effective weight W_{Ceff} of the sample given by core drilling is:

$$W_{Ceff} = Dh\pi[R_C - 0.5d_L]^2$$

The correcting factor C_C for core drilling is:

$$C_C = \frac{W_C}{W_{Ceff}} = \frac{R_C^2}{[R_C - 0.5d_L]^2}$$

The true weight W_R of the sample given by RC drilling is:

$$W_C = Dh\pi R_R^2$$

The effective weight W_{Reff} of the sample given by RC drilling is:

$$W_{Ceff} = Dh\pi[R_C + 0.5d_L]^2$$

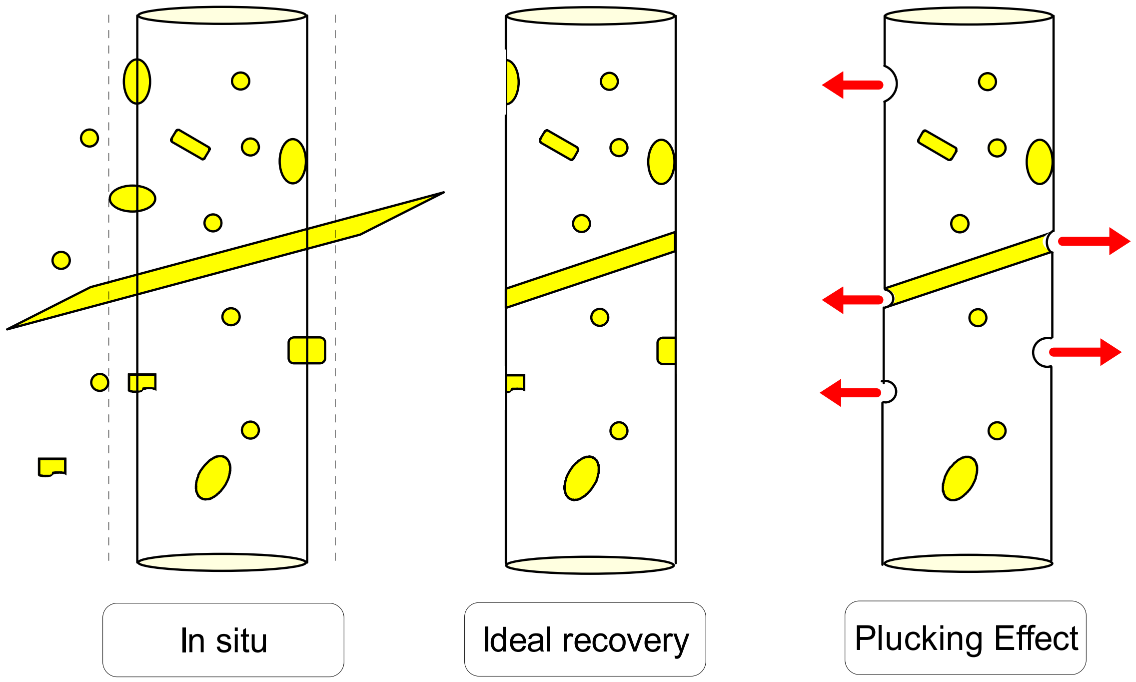


FIG 1 - 'Plucking Effect' generated by a diamond core drilling machine.

The correcting factor C_R for RC drilling is:

$$C_R = \frac{W_R}{W_{\mathrm{Re}\,ff}} = \frac{R_R^2}{[R_R + 0.5d_L]^2}$$

Illustration examples

A NQ core has a diameter of 4.76 cm. The copper content from the core analysis is 1.00 per cent. The average size of chalcopyrite grains is 0.2 cm. What should the true copper content be?

$$C_C = \frac{R_C^2}{\left[R_C - 0.5d_L\right]^2} = \frac{\left[2.38\right]^2}{\left[2.38 - 0.10\right]^2} = 1.09$$

The true copper content is 1.00% x 1.09 = 1.09%

A RC hole has a diameter of 12 cm. The copper content from the analysis is 1.00 per cent. The average size of chalcopyrite grains is 0.2 cm. What should the true copper content be?

$$C_R = \frac{R_R^2}{\left[R_R + 0.5d_L\right]^2} = \frac{\left[6.00\right]^2}{\left[6.00 + 0.10\right]^2} = 0.97$$

The true copper content is 1.00% x 0.97 = 0.97%

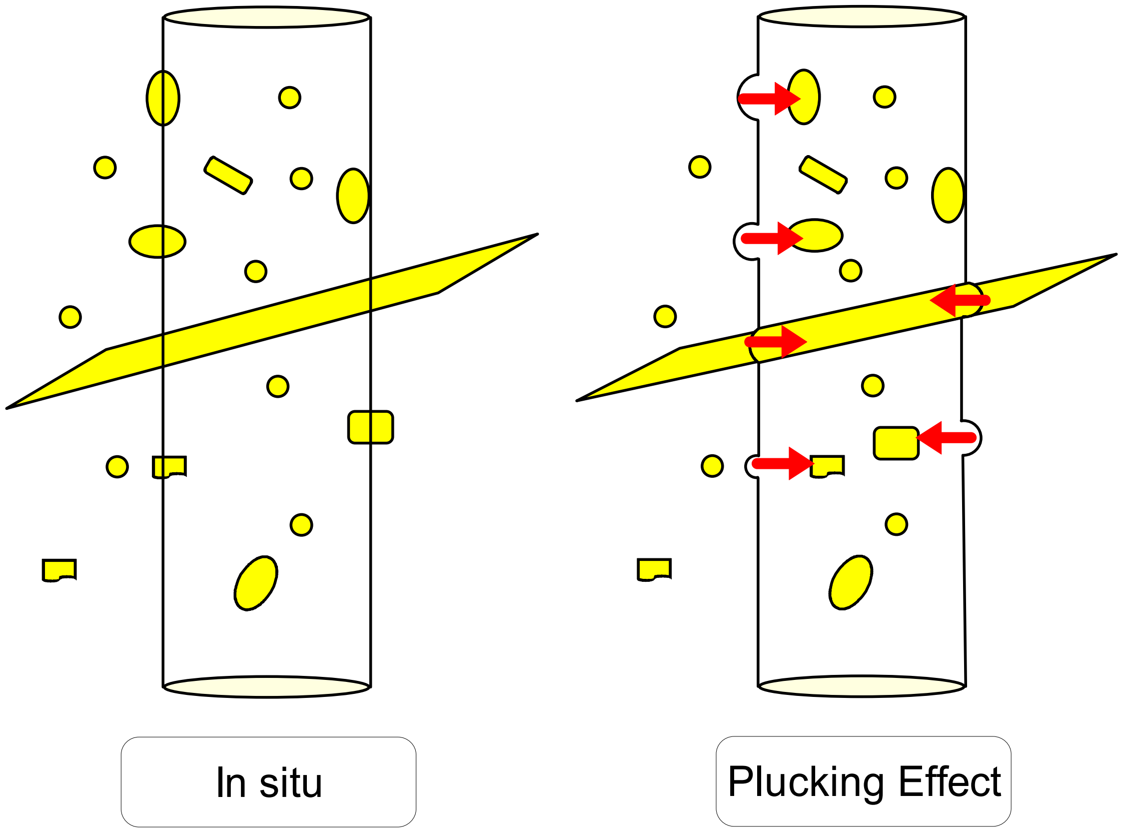


FIG 2 - 'Plucking Effect' generated by a reverse circulation drilling machine, or a blasthole drilling machine.

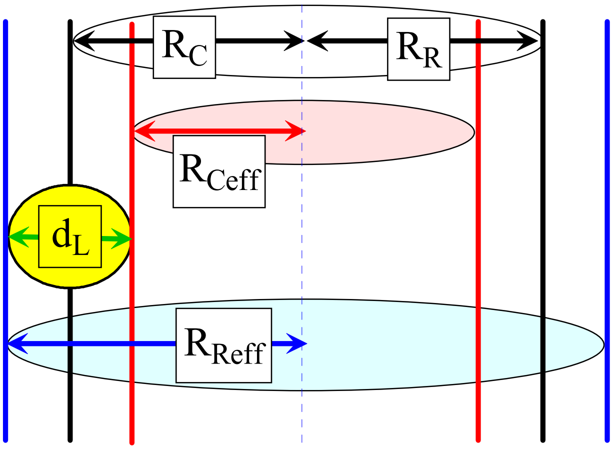


FIG 3 - Definition of terms.

Conclusion: These calculations are approximate, but they clearly show the problem is a substantial one that deserves attention, especially for small diameters, and may explain part of many conciliation problems between the geological model, the mine, and the plant.

SAMPLING CORRECTNESS FOR ORE GRADE CONTROL

Problems associated with blasthole sampling

There are no other places as vulnerable to delimitation, extraction, and preparation biases as the practical implementation of a sampling protocol for blasthole cuttings. This has been a monumental problem for the mining industry from its early days until today. Figure 4 summarises the various areas of concern.

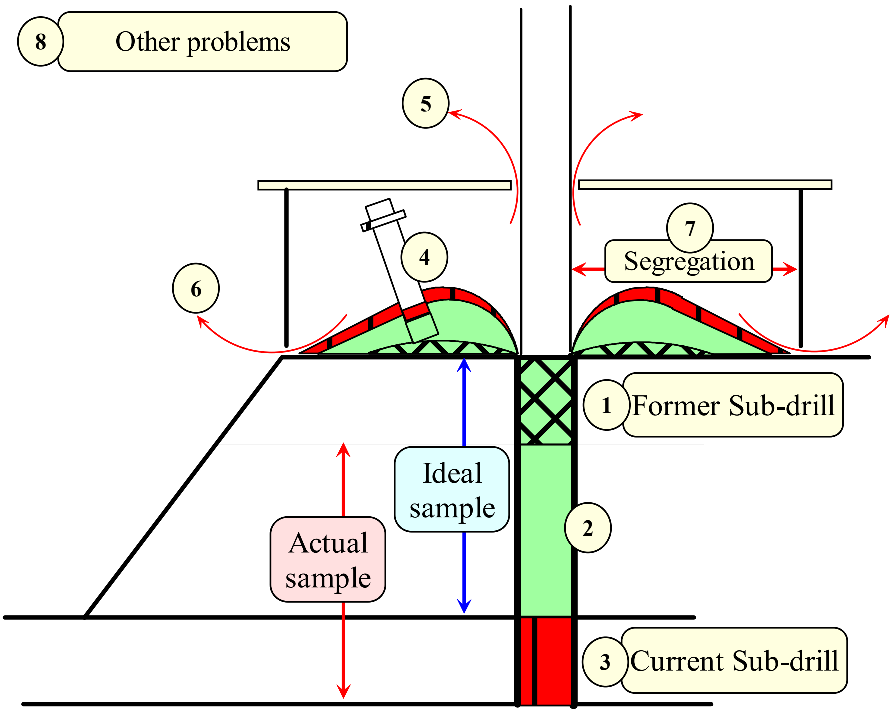


FIG 4 - Illustration of blasthole sampling problems.

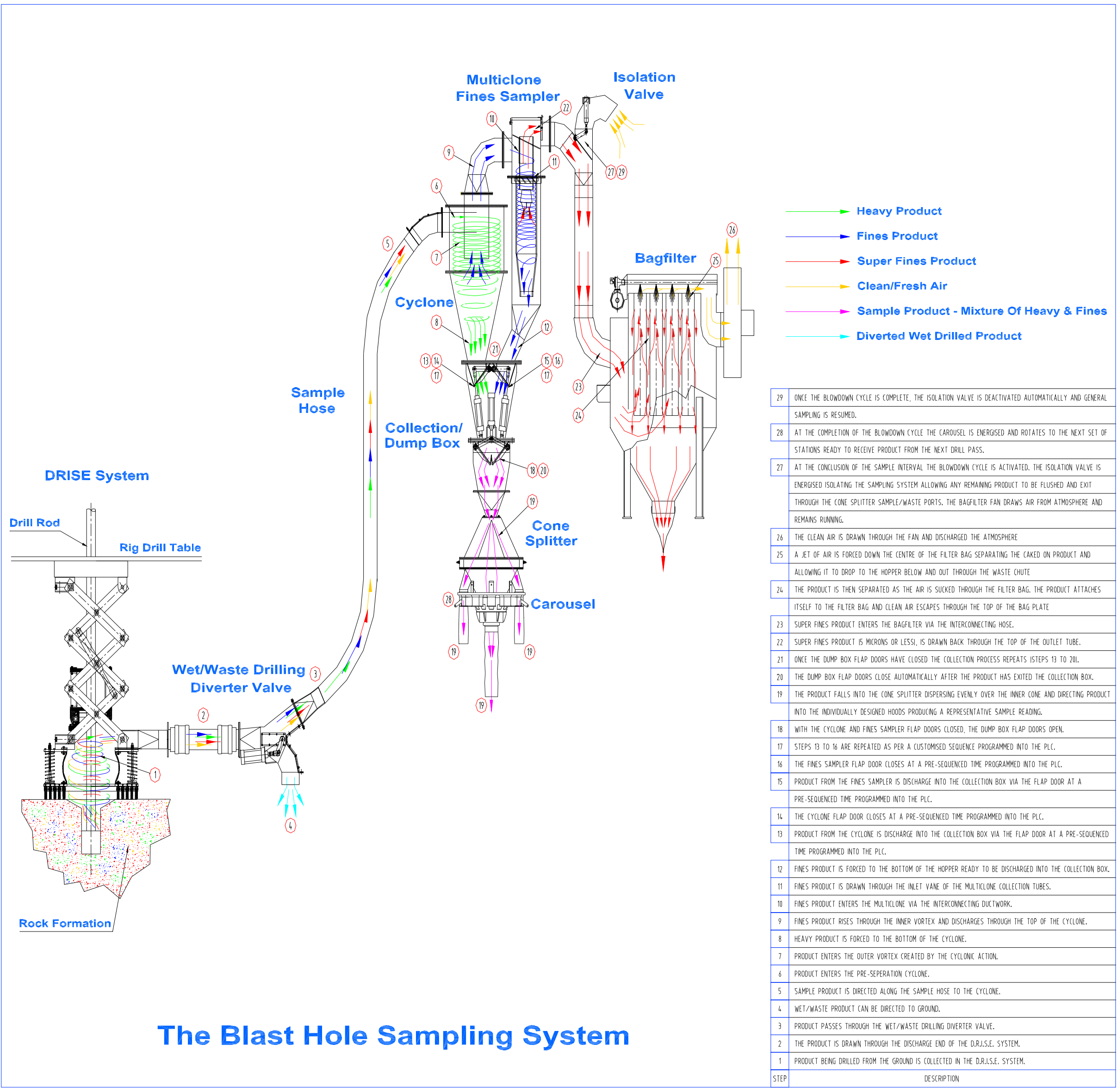
- *Area 1:* Usually the former subdrill, part of the bench, is poorly recovered by the drilling machine because it is made of already broken up material. No matter if it is replacement material, as far as ore grade control is concerned, this material belongs to the sample. The objective of the sample is to represent by proxy what will go to the plant or the waste. Therefore the sample taken by the drilling machine is affected by *extraction bias #1*.
- *Area 2:* Usually, but not always, it is the part of the bench that is best recovered. It is critically important to make sure the drilling machine has a good recovery in this area, otherwise *extraction bias #2* may take place.
- *Area 3:* The subdrill, necessary for mine logistics, must not be part of the sample, since this part of the bench is sent to the mill or the waste as part of the next bench. If the subdrill becomes part of the sample, it leads to *delimitation bias #1.*
- *Area 4:* If a tube is used to collect increments around the pile, it is impossible to collect a complete column representative of all levels. If the subdrill material is not removed, then it becomes the part best represented in the sample, which is wrong. Then, the bottom of the pile, where a lot of coarse fragments have segregated is not represented in the sample. Furthermore, the former subdrill cannot be represented either. This leads to a devastating *delimitation bias #2.*
- *Area 5:* Fugitive fine particles always escape along the drilling rod. This is also a very difficult problem to solve satisfactorily with most automated sampling systems suggested later in this paper. This leads to *preparation bias #1.*
- *Area 6:* Fugitive fine particles always escape below the curtains. It is a must to minimise this loss by maintaining the curtains well. This leads to *preparation bias #2.*
- *Area 7:* The size distribution of the particles is not the same all the way across the pile, therefore a good increment should be a radial increment positioned at random around the pile. A few increments selected around the pile, more or less at the same distance from the drilling rod, necessarily introduce *delimitation bias #3.*
- *Area 8:* This does not refer to any specific area in Figure 4, but summarises other problems that cannot be represented well in the sketch, such as: Loss when the operator retrieves the tube, loss when the driller injects water, loss of particles in fractures during drilling, loss during packaging, etc…

First recommended method: The Metal Craft system

Installing SDS Metal Craft automatic sampling systems, like the one illustrated in Figure 5, on the drilling machines is highly recommended. However, in the past, moisture contents in the range of eight to 15 per cent have caused problems with material hang-up in these systems, as any automatic sampling system requires mechanical collectors to collect all of the drilled cuttings for sampling. This has prompted SDS Metal Craft to develop the new Rotating Cone Splitter for both wet and dry drilling. In dry drilling operations (up to around eight per cent depending upon ore composition) the rotating cone splitter functions in much the same way as the current stationary Cone Splitter except the sampling cone and cutting ports rotate. The cutter design must respect rules listed later in this paper. The main advantage of this device is to be continuous, so the notion of sample increment and lag between increments becomes irrelevant. As a result, the sampling system is proportional since the Weighting Error WE is negligible, which is indeed a good quality. Another advantage is that the stream is correctly presented to the sampling system by following a vertical trajectory that does not compete with gravity. The design of the inspection door is critically important in order to fully inspect the cutters at anytime judged necessary. The disadvantage is to rely on two cumbersome cyclones, promoting cross-contamination problems. But, because of the huge volume of material driven through the cyclones, and because of the possibility of flushing the residual material with compressed air, this contamination problem is minimal.

For moisture contents superior to eight per cent leading to materials prone to hang-up, it is intended to inject water into the hole to bring the moisture content above 15 per cent (or above the percentage that causes hang-up). As the material to be sampled will now be flowing wet, the rotating cutting ports will be critical to prevent any sampling bias from taking place.

This new rotating cone splitter, illustrated in Figure 6, is currently in manufacture at SDS Metal Craft and will be tested early in 2004. For more information, contact Mr Toby Day at Metal Craft (E-mail: Toby@metalcraft.com.au).



STEP	DESCRIPTION
29	ONCE THE BLOWDOWN CYCLE IS COMPLETE, THE ISOLATION VALVE IS DEACTIVATED AUTOMATICALLY AND GENERAL SAMPLING IS RESUMED.
28	AT THE COMPLETION OF THE BLOWDOWN CYCLE THE CAROUSEL IS ENERGISED AND ROTATES TO THE NEXT SET OF STATIONS READY TO RECEIVE PRODUCT FROM THE NEXT DRILL PASS.
27	AT THE CONCLUSION OF THE SAMPLE INTERVAL THE BLOWDOWN CYCLE IS ACTIVATED. THE ISOLATION VALVE IS ENERGISED ISOLATING THE SAMPLING SYSTEM ALLOWING ANY REMAINING PRODUCT TO BE FLUSHED AND EXIT THROUGH THE CONE SPLITTER SAMPLE/WASTE PORTS. THE BAGFILTER FAN DRAWS AIR FROM ATMOSPHERE AND REMAINS RUNNING.
26	THE CLEAN AIR IS DRAWN THROUGH THE FAN AND DISCHARGED THE ATMOSPHERE
25	A JET OF AIR IS FORCED DOWN THE CENTRE OF THE FILTER BAG SEPARATING THE CAKED ON PRODUCT AND ALLOWING IT TO DROP TO THE HOPPER BELOW AND OUT THROUGH THE WASTE CHUTE
24	THE PRODUCT IS THEN SEPARATED AS THE AIR IS SUCKED THROUGH THE FILTER BAG. THE PRODUCT ATTACHES ITSELF TO THE FILTER BAG AND CLEAN AIR ESCAPES THROUGH THE TOP OF THE BAG PLATE
23	SUPER FINES PRODUCT ENTERS THE BAGFILTER VIA THE INTERCONNECTING HOSE.
22	SUPER FINES PRODUCT (15 MICRONS OR LESS), IS DRAWN BACK THROUGH THE TOP OF THE OUTLET TUBE.
21	ONCE THE DUMP BOX FLAP DOORS HAVE CLOSED THE COLLECTION PROCESS REPEATS (STEPS 13 TO 20).
20	THE DUMP BOX FLAP DOORS CLOSE AUTOMATICALLY AFTER THE PRODUCT HAS EXITED THE COLLECTION BOX.
19	THE PRODUCT FALLS INTO THE CONE SPLITTER DISPERSING EVENLY OVER THE INNER CONE AND DIRECTING PRODUCT INTO THE INDIVIDUALLY DESIGNED HOODS PRODUCING A REPRESENTATIVE SAMPLE READING.
18	WITH THE CYCLONE AND FINES SAMPLER FLAP DOORS CLOSED, THE DUMP BOX FLAP DOORS OPEN.
17	STEPS 13 TO 16 ARE REPEATED AS PER A CUSTOMISED SEQUENCE PROGRAMMED INTO THE PLC.
16	THE FINES SAMPLER FLAP DOOR CLOSES AT A PRE-SEQUENCED TIME PROGRAMMED INTO THE PLC.
15	PRODUCT FROM THE FINES SAMPLER IS DISCHARGE INTO THE COLLECTION BOX VIA THE FLAP DOOR AT A PRE-SEQUENCED TIME PROGRAMMED INTO THE PLC.
14	THE CYCLONE FLAP DOOR CLOSES AT A PRE-SEQUENCED TIME PROGRAMMED INTO THE PLC.
13	PRODUCT FROM THE CYCLONE IS DISCHARGE INTO THE COLLECTION BOX VIA THE FLAP DOOR AT A PRE-SEQUENCED TIME PROGRAMMED INTO THE PLC.
12	FINES PRODUCT IS FORCED TO THE BOTTOM OF THE HOPPER READY TO BE DISCHARGED INTO THE COLLECTION BOX.
11	FINES PRODUCT IS DRAWN THROUGH THE INLET VANE OF THE MULTICLONE COLLECTION TUBES.
10	FINES PRODUCT ENTERS THE MULTICLONE VIA THE INTERCONNECTING DUCTWORK.
9	FINES PRODUCT RISES THROUGH THE INNER VORTEX AND DISCHARGES THROUGH THE TOP OF THE CYCLONE.
8	HEAVY PRODUCT IS FORCED TO THE BOTTOM OF THE CYCLONE.
7	PRODUCT ENTERS THE OUTER VORTEX CREATED BY THE CYCLONIC ACTION.
6	PRODUCT ENTERS THE PRE-SEPERATION CYCLONE.
5	SAMPLE PRODUCT IS DIRECTED ALONG THE SAMPLE HOSE TO THE CYCLONE.
4	WET/WASTE PRODUCT CAN BE DIRECTED TO GROUND.
3	PRODUCT PASSES THROUGH THE WET/WASTE DRILLING DIVERTER VALVE.
2	THE PRODUCT IS DRAWN THROUGH THE DISCHARGE END OF THE D.R.I.S.E. SYSTEM.
1	PRODUCT BEING DRILLED FROM THE GROUND IS COLLECTED IN THE D.R.I.S.E. SYSTEM.

FIG 5 - Sketch showing the principle of the Metal Craft blasthole sampling system.

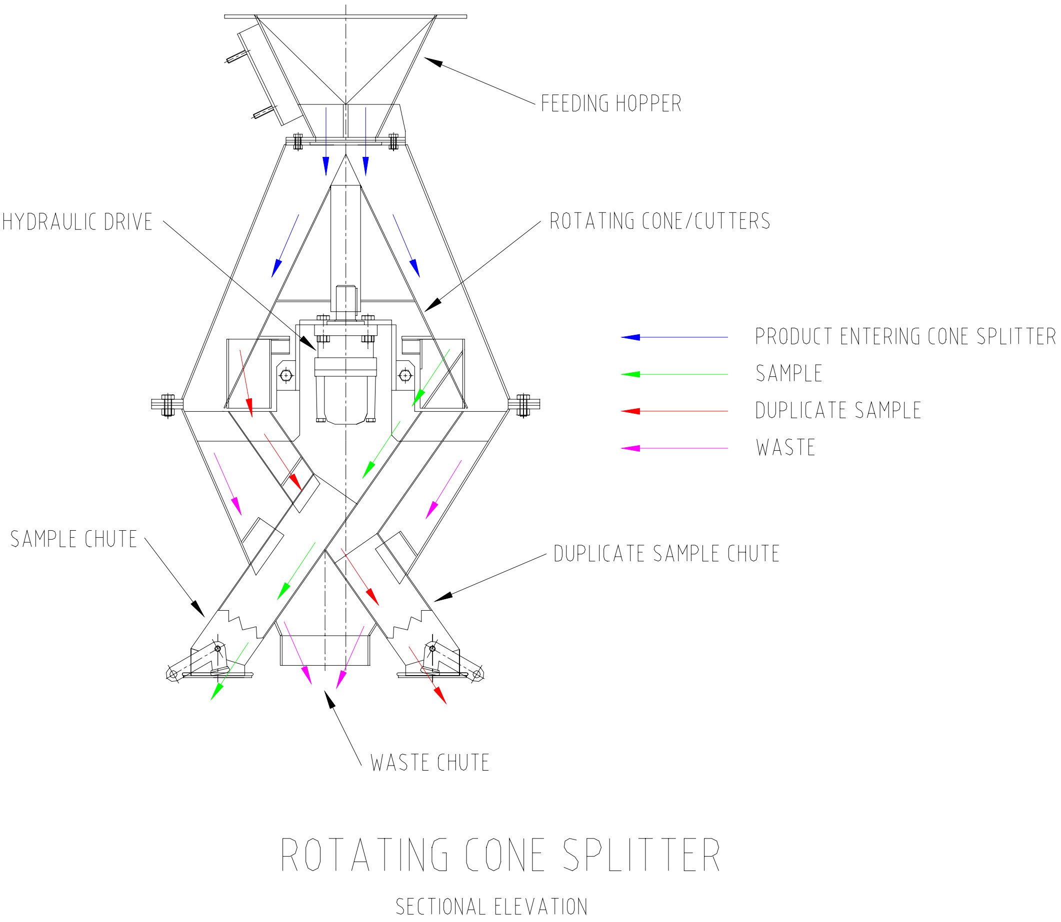


FIG 6 - Illustration of a new Metal Craft sampling system. The existing system is similar, however the two cutters are stationary.

Second recommended method: The DrillSampler^{tm} from Harrison R. Cooper systems

The DrillSampler^{tm} for automatic blasthole sampling consists of a stem collector located around the drilling rod, enabling all the drill cuttings to be carried in air-entrained flow to a horizontal half-arc rotating sampler located under the deck of the drilling machine. Chips are directly sent to the sampling system without passing through a series of cyclones, minimising sources of cross contamination and excessive problems associated with the moisture content. Yet, the moisture content should not exceed seven to ten per cent. The sampling ratio can be easily adjusted by changing the time between cuts. However, under no circumstances should the sample be made of less than 30 cuts. The sampling system is illustrated in Figure 7. The horizontal positioning of the cutter is an invitation for plugging problems, but field experience demonstrated it was a minor problem if the unit is properly cleaned and maintained at the end of each working shift. The technology of this system has been the object of intensive research and the last commercialised units have shown excellent maturity in all details. For more information on this sampling system, contact Mr Harrison Cooper at hcooper@hrcsystems.com and view http://www.hrcsytems.com .

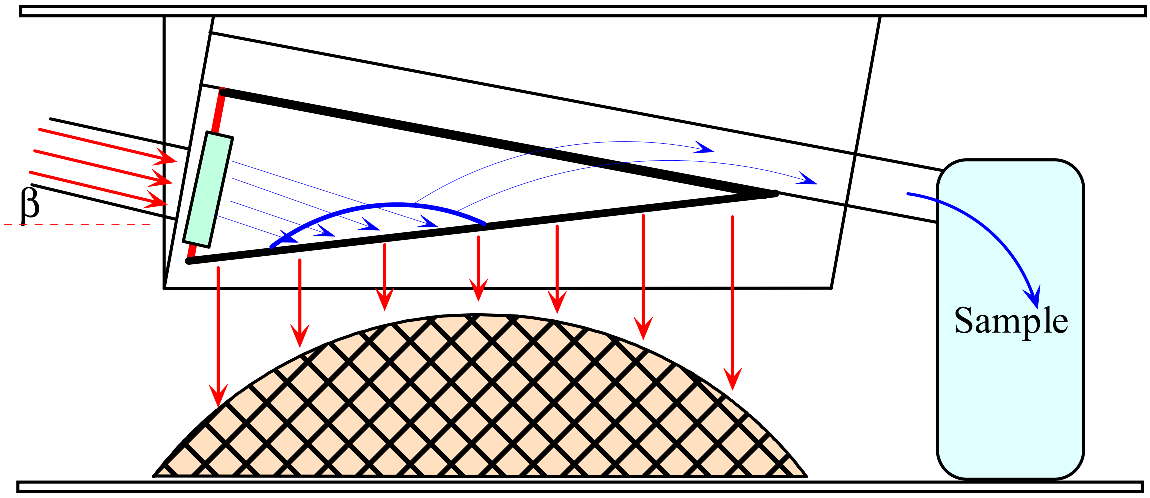


FIG 7 - The DrillSampler^{tm} from Harrison Cooper for automatic blasthole sampling, installed under the deck of the drill rig deck.

Third recommended method: The Codelco IM2 system

The blasthole automated sampling system illustrated in Figure 8, built for Codelco, consists of two radial cutters positioned around the drilling rod. The positioning can be randomised to some extent. The material collected inside the radial cutters is sent at regular intervals to the sample using a pneumatic drive. The advantage of this system is that it may work well with any kind of moisture content. However, for the radial cutters to be correct, it necessarily requires the collection of a very large sample. This is a serious limitation for the huge blastholes performed in the copper industry. Intermittent sampling, closing the cutters for short periods of time, could minimise the sample mass to some extent. The sample is also limited to two increments collected around the pile, which does not minimise segregation problems effectively. If the system could slightly rotate around the pile, at least within a 45^{o} angle on both sides, it would be a tremendous improvement. The great advantage of this concept is both the absence of cyclones and the absence of the difficult-to-maintain stem collector. This concept is more likely to lead to the loss of some very fine size fractions, but this problem can be minimised with the use of effective curtains around the system. This pragmatic system is a beautiful example of how aggressive Chilean technology has been in that field during the past few years. It is the author's opinion this system can evolve with time, and perhaps lead to the ideal solution for blasthole sampling, as it does not seem to interfere too much with drilling productivity.

Conclusion

These three new blasthole sampling systems are far from being perfect. They are based on clever, totally different, principles. At this stage it is not clear yet which system will prove to be the most reliable and easiest to use: These qualities are the key for success. These three systems lead to correct samples, which are representative of all the size fractions involved. They represent a major breakthrough in ore grade control for the mining industry.

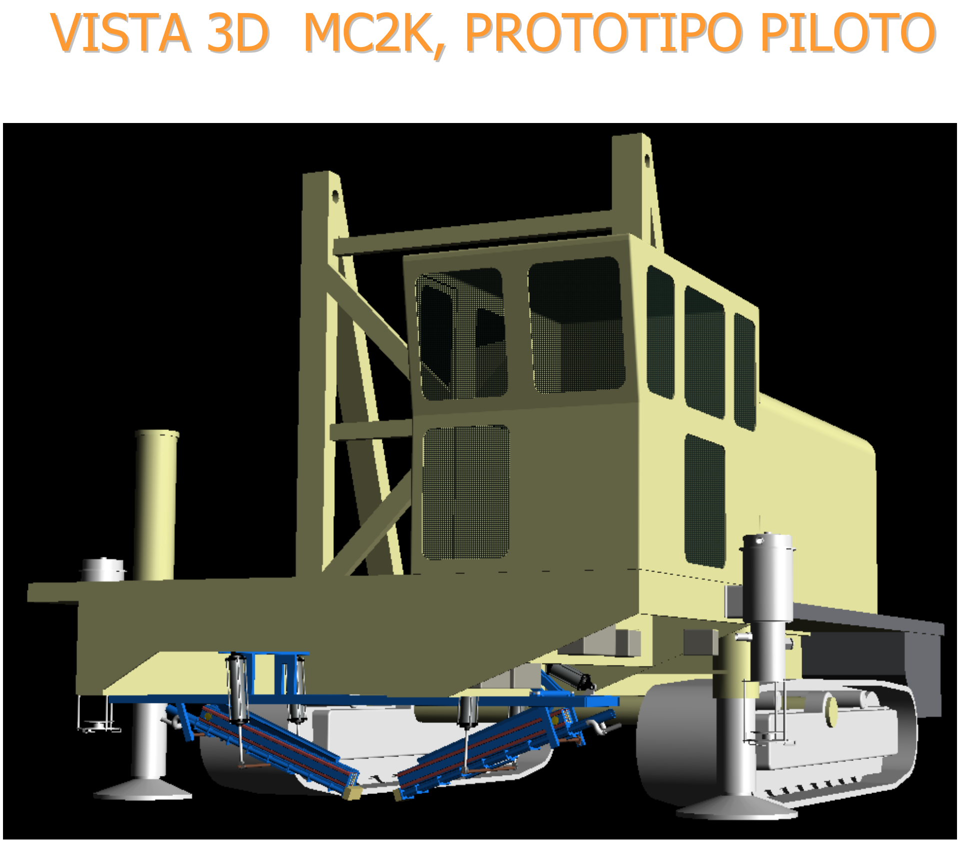


FIG 8 - The Codelco-IM2 blasthole sampling system, installed under the deck of the drilling machine.

SAMPLING CORRECTNESS AT THE PLANT

Plant sampling: A breakthrough from Chilean technology

In a paper published in 2002, Pitard addressed difficulties encountered in the sampling of large streams in floatation plants or CIL circuits, (Pitard, 2002). Secondary and tertiary samplers are equally important, and the most popular sampler used in the mining industry for small flowing streams is the rotating Vezin sampler. Unfortunately, many Vezin samplers are built incorrectly, with poorly designed cutter blades and inspection doors that are too small and installed at the wrong place. Furthermore, the rotation speed is often excessive and does not comply with guidelines given in the Sampling Theory. Recent years have been marked by the venue on the market of new, superior Vezin samplers, to the credit of two Chilean manufacturers: ie TecProMin Lta: Juan Carlos Michels V. (**Michels@tecpromin.cl**) and Process Chile: Miguel Yanez R. (**tmsa@entelchile.net**). Let's discuss areas where these systems are superior to others.

Cutter blades

Cutter blades, the correctness of which is so critically important, have been designed by following Pitard's recommendations summarised in Figure 9 for a straight-path cross-stream sampler. Of course, for Vezin sampler the cutter edges must be radial with respect to the centre of rotation.

- A very steep angle for the blades is necessary to prevent some material that does not belong to the increment from climbing the leading blade: $\alpha = 20^{o}$
- A very narrow, flat area on the top of the cutter edges is highly recommended, to prevent rapid wear: Value of Y depends on flow rate and on the size of the fragments.
- The space available inside the cutter is always larger than the cutter opening: W<X<Z.
- Only one possible position for the cutter blades is allowed, ensuring perfect symmetry of cutter edges at all times.
- The cutter blades are made of very hard steel to prevent rapid wear.

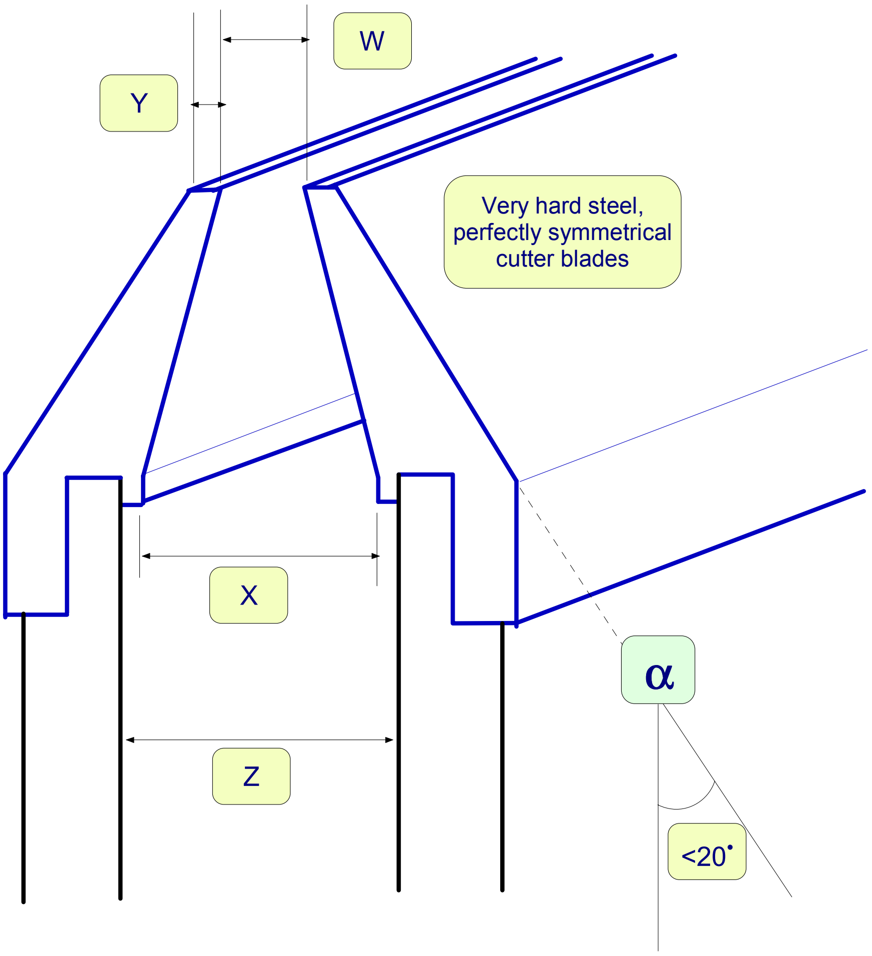


FIG 9 - Recommended design for the cutter blades of a straight-path cross-stream sampler.

Cutter opening and cutter speed

Figure 10 illustrates a correct Vezin sampler. At the closest stream point from the centre of rotation, the cutter opening W should be larger than the minimum acceptable $W_0 = 3d + 1$ cm, where d is the size of a screen opening retaining no more than five per cent by weight of the fragments in the stream. At the farthest stream point from the centre of rotation, the cutter should under no circumstances travel faster than 45 cm/second for Vezins with a diameter larger than 60 cm, and no faster than 30 cm/second for Vezins with a smaller diameter.

Length of the cutter

Figure 11 shows the necessary safety factor for the length of the cutter in a half-arc rotating sampler: On each side of the intercepted stream a minimum 5-cm length is recommended to allow bouncing material to be recovered, preventing an extraction bias from talking place.

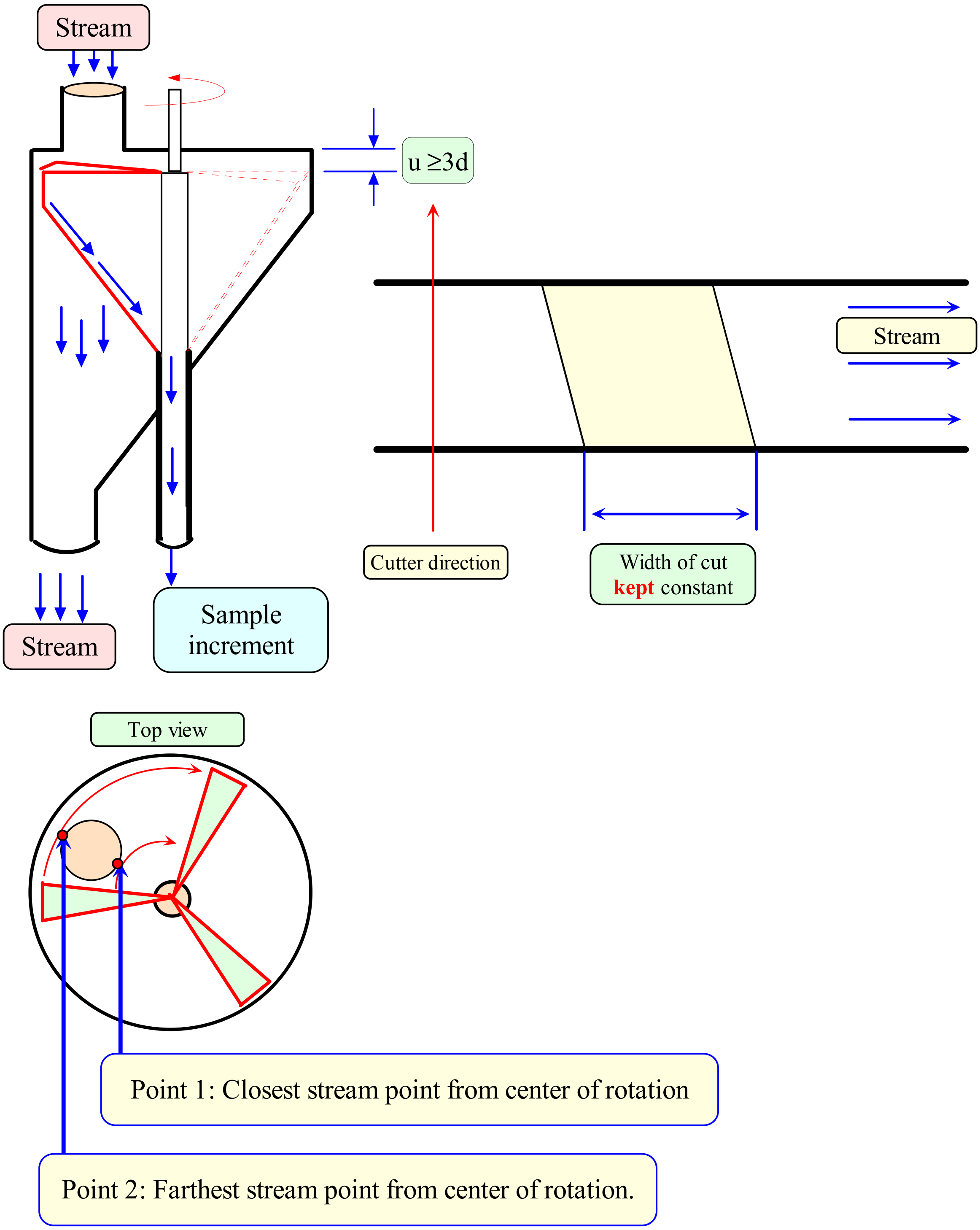
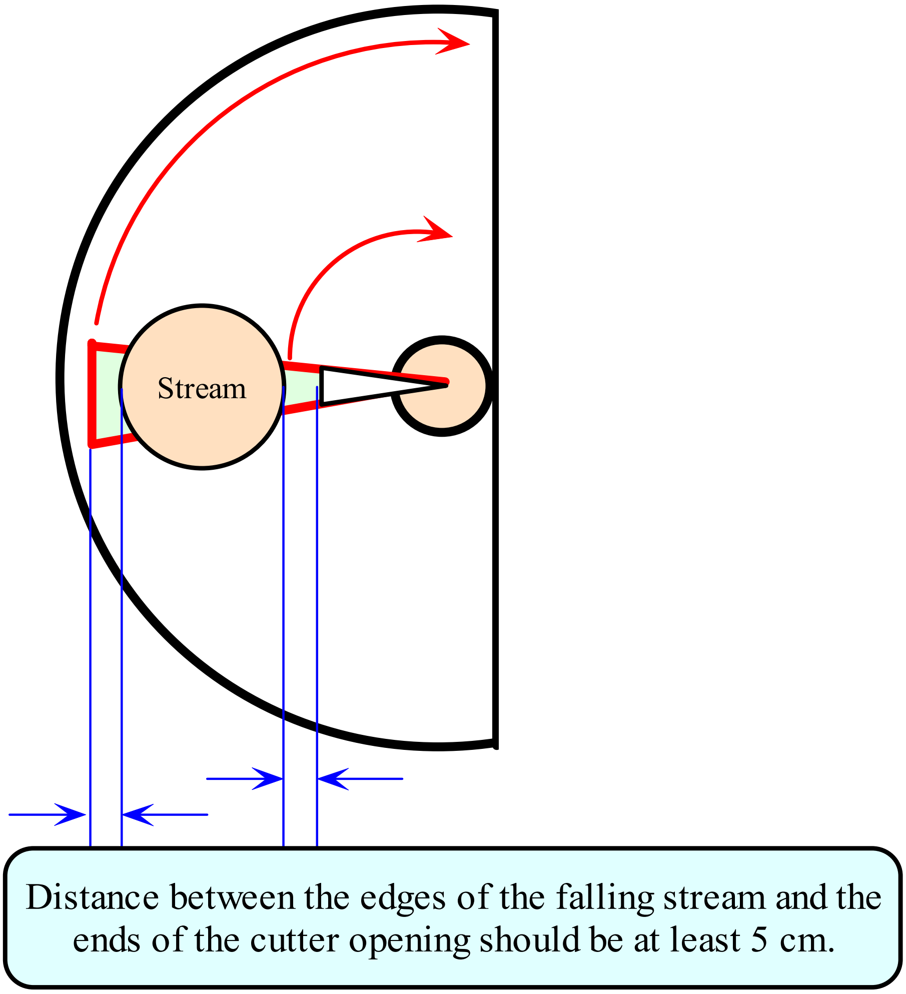


FIG 10 - Illustration of a rotating Vezin sampler.



Distance between the edges of the falling stream and the ends of the cutter opening should be at least 5 cm.

FIG 11 - The entire stream must be cut, including a safety factor on each side of the stream.

Inspection door

Figure 12 shows the usual, unacceptable inspection door, and what it should be. When the inspection door is opened, it is essential to see the entire cutter for at least one third of a full rotation. A screen must also be installed under the inspection door to prevent the operator from inserting his hand when the cutter is rotating.

NEW LABORATORY SUBSAMPLING SYSTEMS

For many years laboratory subsampling has been a very time consuming, labor intensive, and operator dependent operation. Furthermore, commercial laboratories competing with each other found it economical to take short cuts on the necessary subsampling protocol, generating a form of fraud made in the name of economical practicality. Such practice has not been good for many exploration programs around the world, nor for effective ore grade control at the mines. Intuitively, automated sample preparation facilities were the key to solve these difficult problems. Many of these facilities were built around the world, but at an extravagant building and maintenance cost. During the last few years, effective new systems arrived on the market, for the best.

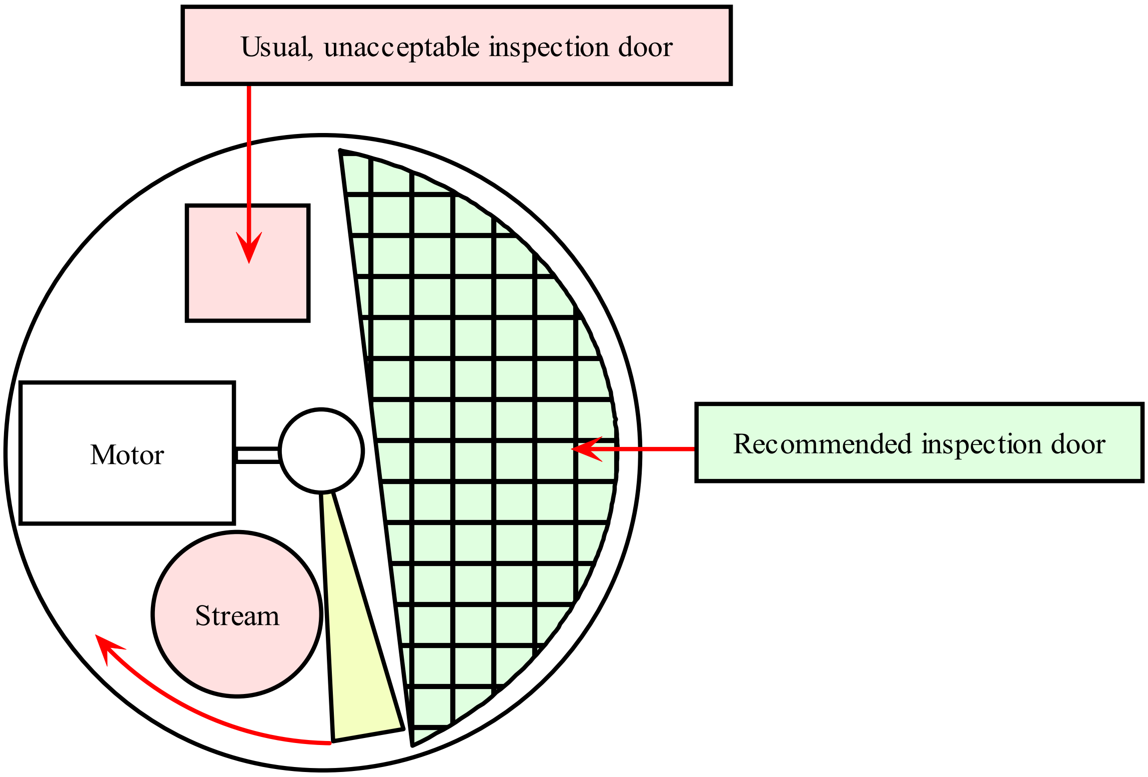


FIG 12 - The inspection door must be very large.

A recommended sample preparation facility: The Rocklabs mechanised system

Rocklabs continues to expand the range of its famous mechanised and automated sample preparation systems. These systems are actually customised for the particular needs of one mining operation. This was the key for success: Building systems to fulfill requirements for a given subsampling protocol, instead of adapting a protocol for the existing mechanised or automated system. A typical setup is illustrated in Figure 13, where 'A' is a *Boyd* jaw crusher, 'B' is a *CRM* continuous ring mill, 'C' is a *RSD* rotating sample divider, and 'D' is the final *CRM* continuous ring mill. The entire sequence ABCD consists of a single series of machines working in unison, minimising the need for manpower and along the way eliminating human mistakes. Cleaning between samples is performed with compressed air at all key points. These systems are very reliable and cost effective. They represent a giant step toward quality.

CONCLUSION

Today, there are excellent sampling systems available on the market, and there is no longer any excuse not to perform a good sampling job in various areas listed in this paper. Manufacturers of sampling equipment around the world should modernise their existing product, and promote more correct and reliable systems. Such changes are wise and in their best interest. However, manufacturers, engineering firms, geologists, miners, metallurgists, and chemists all need to refer to updated, better international standards on sampling: A good expertise in conventional statistics does not imply a good expertise in sampling.

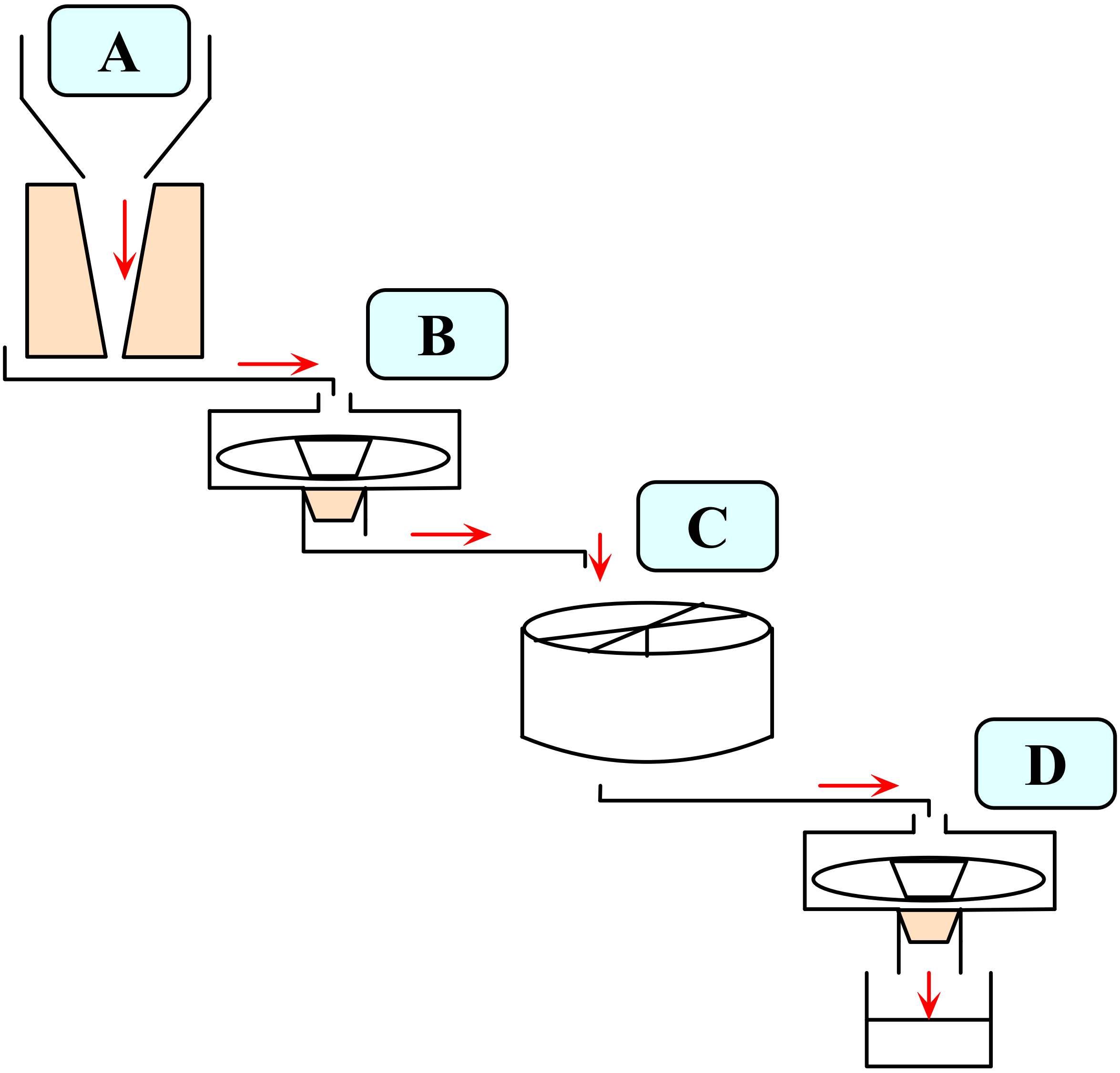


FIG 13 - A typical Rocklabs mechanised sample preparation system.

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