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TOS forum

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WCSB7

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A distinct pleasure...

It is indeed a pleasure to edit this new periodical. Assessment of the value and merit of a new publication must include many factors, of which the scientific standard of contributions probably looms very high for many readers, the number and scope of contributions, circulation numbers, the inevitable economic prospects in launching a new periodical, reactions from the readership. However, the personal and professional value for each single reader is undoubtedly the singular most important factor determining the long-term success or failure: Why am I reading another new publication? Do I have the time for this?

Although still very early in the life of *TOS forum*, these are already factors of keen interest for the Editor and the Publisher both. And we are greatly satisfied—with the reactions shown, indirectly as well as explicitly, so far... In fact, these crucial indicators prompted a few directed solicitations, in the form of open invitations to report here on the personal and institutional/company impressions and reactions to both WCSB6, Lima (2013) and SAMPLING2014, Perth (2014). This *TOS forum* issue 3 both carries a personal assessment of WCSB6, submitted "from a young professional from the mining industry" as well as no less than three reports on SAMPLING2014, which at the time of writing is not even two month ago. Talk of convenient timing! These testimonies are meant to provide salient information to all in the world sampling community that, for one or other reason, unfortunately could not personally attend these events, but also to colleagues outside our own narrow circles, for example to the NIR spectroscopy community in particular, which has adopted a professional interest in all manners of sampling recently—a pleasure to behold. In this endeavour these contributions fulfil several of the main communication objectives of the *TOS forum*—a pleasure to behold.

Among the strict scientific contributions, please find the second instalment of Francis Pitard's treatment of "A new System of Units", and a "review of sampling and monitoring protocols related to radioactive elements in fractured rock aquifers" by Gaather Mahed, South Africa. Another contribution, from Brazil, is from the mining sector with a theme that surely must interest a very wide audience, perhaps not only in this sector: "Illusionary reconciliation". Similarly, *TOS forum* issue 3 carries a detailed summary of a recent PhD from a parallel, and not always obviously inter-related sector, that of commodity sorting. It turns out that there is a more than subtle connection to the Theory of Sampling after all... How to sort in a reliable manner, if/when the critical calibration is not based on representative sampling the lot eventually to be sorted in its entirety? Perhaps, or perhaps not, surprisingly, this issue is far from always taken care of with sufficient professionalism (TOS) writes the newly minted PhD Chistoffer Robben.

The featured piece of *TOS forum* issue 3 is the *Aloha Sampler*—a newly developed concept, and equipment, which will stun the reader by its "ingenuity in simplicity". It has been the Editor's wish to present the *Aloha Sampler* ever since WCSB6, but several distracting and delaying issues have intervened—but this is now a moot point: ENJOY reading about the solution to a very difficult objective: representative sampling of surface waters.

The reader will also find two illuminating opinion pieces from Dominique Francois-Bongarcon and Claudia Paoletti, both addressing the needs of the world sampling community but from diverse points-of-view: the one from an organisational viewpoint: Samplers, what needs to be done?, the other summarising a decade of frustration, giving insight into what, among other mandates, is driving the GMO Unit at the European Food Safety Authority (EFSA).

This issue appears to be a perfect example of the scope for this new communication platform for the world sampling community—between conferences. It is to be hoped that the distinct pleasure editing and publishing *TOS forum* translates into also making it—a distinct pleasure—reading it. You tell us!

P.S. *TOS forum* issue 4 will carry a plethora of information regarding the World Conference on Sampling and Blending, WCSB7, Bordeaux, 10–12 June 2015; you will find a reference to the conference homepage on page 2 in this issue. At the very least fix this week in your calendar now ;-)

The Aloha Sampler™ and its inventor, Chuck Ramsey. Read more on page 12.

Be part of the next issue of *TOS forum*!

We welcome contributions to *TOS forum*: articles, letters, comment, news or news of PhD projects for the PhD Presentations column.

TOS forum Editor, Kim Esbensen, would be pleased to discuss any ideas you may have and to receive your contributions.

EDITOR
Kim H. Esbensen (Geological Survey of Denmark and Greenland (GEUS), Copenhagen, and ACABS research group, Aalborg University, campus Esbjerg, Denmark; ke@geus.dk)

PUBLISHER
Ian Michael (ian@impublications.com)

6 Charlton Mill, Charlton, Chichester, West Sussex PO18 0HY, UK.
Tel: +44-1243-811334;
Fax: +44-1243-811711;
E-mail: subs@impublications.com

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Editorial correspondence to Kim Esbensen, ke@geus.dk. All production correspondence should be sent to *TOS forum*, 6 Charlton Mill, Charlton, Chichester, West Sussex PO18 0HY, UK, Tel: +44(0)1243–811334, Fax: +44(0)1243–811711, e-mail: ian@impublications.com.

Future challenges and research: theory of sampling (TOS)

D. Francois-Bongarcon
E-mail: dfbgn2@gmail.com

Well organised around the WCSB conferences and the bi-annual sister conference in Perth, Australia, the sampling community has never been as dynamic as today. Debates are rich and productive, disagreements are usually handled in a constructive and friendly manner, but research, academic as well as industrial, is still needed on a large number of subjects. Universities are starting to get on board in a more structured way, with the result that a growing number of students around the world are now exposed to TOS during their studies. But the future of TOS is still in the making and we all have a duty to foresee what is needed, and to help and contribute as much as possible.

Theory

On the theoretical front, the last two decades have been particularly productive. Models for the liberation factor were finally proposed that have brought the theory to an advanced stage; such models are now being validated by numerous experimental applications. Methods for realistic and relevant calibration of the thus *completed* variance formulas are being vigorously investigated and improved.

Teaching is increasingly more and more efficient, and typically nowadays stripped of unnecessary mathematical difficulties while, simultaneously, the importance of the qualitative concepts (correctness, distributional heterogeneity) are properly emphasised. Theoreticians are still active and keep following the practical developments to safeguard them from evolving in the wrong direction. Finally, in-depth mathematical modeling research is still going strong with the potential promise of even better applications of TOS in the future.

But challenges also still exist in the background. Augmented models, as well as practical application methods, do not always generate immediate consensus, leaving the impression that TOS and its uses still require some amount of cleaning. Similarly, older developments are not always questioned enough, even though sometimes under attack or suspicion from some of the TOS community. For instance, disagreements still occur as to practical approaches between "purists" (advocating segregation-free methods) and those advocating inclusion of residual segregation effects in the predictive results. Antiquated methods are still proposed to the public even though the underlying techniques have evolved drastically and better tools are in some cases available.

As a good example already described in a paper, Gy's rudimentary, graphical variographic analysis of processes, as it is applied today, uses a flawed splitting of components and would benefit from being overhauled using modern geostatistical knowledge of the true meaning of variogram modeling and its limitations. Another example (along the same line) is the confusion, deep-rooted in the early works, between sampling sensu-stricto (TOS) and in situ measurements, e.g. for 1-D streams (geostatistics). These theoretical flaws and imperfections run the risk of exposing TOS to easy criticism it does not need, and the non-academic practitioner is often left to his/her own devices to sort out the why and the what of such state of affairs.

Overall, however, the knowledge and understanding of the incredible power of TOS have progressed quite satisfactorily, and it can be said it is experiencing its "golden age" in these years. But from the outside, it is sometimes a quite different story that is perceived. As any good "new" science, TOS at times hits a wall of incomprehension, or adverse protectionism from domains where it has not traditionally been applied (yet), even if this is often where it logically is needed the most. Sampling of grain (outside Canada) comes to mind as a striking example, but it is probably far from being the only domain where this is the case. Also the coal mining industry has not been spared from this point of view, even though it has, to a large degree, been the crib of many excellent sampling methods and inventions for over more than a century. It is nevertheless important to acknowledge that it is only in comparatively well-defined sectors that such reservations are found. Industries traditionally dependent upon good sampling, such as the gold, precious metals, REE and base metal mining industries, have kept growing in their confidence in what TOS has to offer, and commendable efforts and progresses have been witnessed there in renewed dedication to much more reliable sampling. This contemporary evolution forms a close parallel to the one geostatistics has followed earlier.

Practice

Also on the practical front, things are definitely evolving towards a brighter side. New, better sampling devices are regularly derived and invented, progressively closing the gap where no correct samplers were available before. Incorrect sampling devices are now more effectively and more easily identified, and retrofitted solutions or completely new TOS-compliant devices are offered to the users. Many innovations have recently offered better solutions, e.g. for sampling of pulverised dry material and for the sampling of running conveyor belts, while the sampling of conveyed powders and slurries in pressured pipes is already being engineered.

The concept that automatic samplers are ordinary devices that need no further attention save being maintained, is rapidly losing ground to the correct understanding that all sampling systems are precision devices that must be respected in their complete integrity, need to be regularly monitored, verified, cleaned and periodically inspected in an accountable manner. Still, however, our professional conferences are always

blessed with the occasional, hilarious slide of some appalling system... Alas, miracles do not happen often in the TOS community, but, thanks to God, such "humorous sampling" that keeps showing up does so only in small enough proportions for everybody's comfort.

Now readily available everywhere, new teaching material is increasingly emphasising the practical concepts and understanding that are essential for reliable sampling. Excuses for poor sampling, even in unfavourable industrial situations, are losing ground every day.

At the same time, new, experimental calibration methods for the numerical models are being investigated with very promising results, e.g. the use of series of samples taken from hierarchical size fraction setups with no influence from the grouping and segregation error (GSE).

Research

Regarding research, efforts are still very much needed, as ever. Whether it is a problem of lack of sponsorship from the relevant industries, or a consequence of poor appreciation of TOS as a desirable element on regular academic curricula in universities, academies and schools teaching geology, mining engineering, metallurgy or chemistry, is not clear. Even though there are specific exceptions (see below), many such seats of learning and teaching are generally failing in promoting this relevant research. Yet, potential fundamental and applied research subjects do exist in large numbers, at all academic levels, as does the availability of competent academic and industry research directors in our sampling community. There are still only a few handful of university degrees and research projects linked directly to TOS around the world, and a continued, serious effort is needed which would be very favourable to the above mentioned industry sectors. A clear objective for the future, which in this context could be said to start with WCSB7, is to forge a much improved alliance between industry and academia in these matters. It should be emphasised, however, that several oases exist already on this path, doing well (locally doing much better) than this lament, and which are nicely distributed all over the world, notably in South Africa and Australia, in Scandinavia, Brazil, Chile...

A list of possible research subjects would include (list certainly not restrictive):

- Comprehensive study of the "natural degree of segregation" of a lot of particulate matter, and reliable estimation thereof.
- A survey of the types of sampling methods, samplers or situations that are still not available in a TOS-correct form, e.g. sampling in slurry tanks, sampling of large stockpiles or of large bodies of liquids.
- The domain of validity of TOS, and whether, and where, it can be transgressed—or not.
- Effects of tuning the speed of a rotary splitter.
- Revisiting and ranking of sample splitting methods.
- Comprehensive surveys of industrial needs and practices.
- The economic impact of poor sampling in a variety of real-life scenarios.
- Spear sampling—a much used, incorrect sampling technique: empirical investigations.

And more…

Conclusions

It is comforting to write in *TOS forum*, because its very existence is a definite proof of well-being for our community. As can be inferred from the quality of our conferences, we are indeed blessed with having brought our discipline to a formidable scientific high, and with a current all-time record in degree of recognition and appreciation from all walks of science, technology and industry.

To address the needs for a sustained evolution, we must nevertheless face the following issues:

- TOS must be taught much more systematically in many more technical schools, universities and similar—primarily to students and not only to already working professionals.
- The idea that progress in TOS, or more simply good sampling, however desirable, should cost nothing, must be revisited by everyone involved. Obviously this is an erroneous perception that **must** be changed.
- Research in TOS and applications needs to be promoted and sponsored more proactively.
- The economics of sampling must be made clearer to all parties involved. There is huge benefit in furthering this objective—the "money argument" is always getting a hearing in management circles.
- Theoreticians must reach a general consensus on issues of fundamental disagreement.

Facing these critical issues cannot be limited to simply acknowledging their rightness. Words are fine—but actions are needed, and influences must be used. This should be felt as the responsibility of everyone in our community, and with the advent of the TOS forum and the next conference in Bordeaux, the time is particularly right for meeting and agreeing on an increased, concerted effort along the avenues described above.

Note from the editor

Continued efforts must be made strengthening the sense of one, united sampling community. At WCSB6 some "murmurings" were accidentally overheard, that "these conferences are incorporating much too much applications that are **not** related to mining..." This is a fatal misunderstanding! On the contrary, it is vital—also for the mining industry—that the ever broadening canvas of the conferences and our work between them, continues to be stimulated and inspired by the widest possible scope of theory, research and applications from all sectors in science, technology and industry.

A French mining engineer, Dr Dominique François-Bongarçon has devoted his research time to Gy's theory of sampling after a career in Geostatistics. The main areas of expertise of his two consulting companies, AGORATEK International and GEOMATEK (Brazil), include sampling equipment design, sample custody, QA/QC, and reference materials.

A young professional's first encounter with the world sampling community. Report from World Conference on Sampling and Blending WCSB6, 2013, Lima, Peru

Karin Engström
Quality Control and Method Development, Luossavaara-Kirunavaara AB (LKAB), Kiruna, Sweden

As a fairly new Quality Management MSc graduate, I have been working with method development within QC, Sampling and Analysis control for a few years. In a large mining company like LKAB, sampling is really one of the key aspects to QC, but the few of us working in this area *always* meet a lot of skepticism to the perceived efforts (in time and resources) that sampling requires. And at the same time, the view regarding laboratory equipment is the total opposite, where traditionally a lot of money and other resourses are spent to improve capacity and precision without any questions asked. Regarding the primary sampling, far too often I have heard the phrase, "Why don't we just use a shovel, how much do you need for the analysis?".

At LKAB we have begun systematic work on developing our primary sampling procedures, mainly focused on how to improve representativity. The only "problem" is to get everyone from drillers, process engineers, project leaders, geologists, laboratory personnel and managers to understand how important it is to collect a representative primary sample (both from stationary or process lots), and that it is well worth the time and effort. In almost every situation, the first reaction to our recommendation for sampling is positive and almost everyone trusts our judgement on how to perform representative primary sampling. But when it comes to the practical side of things and the driller realises he might have to wait a few minutes before starting to drill, for the sample to be collected, the complaining starts. Or when the project manager realises that a Vezin sampler is twice the cost of a hammer-sampler, our efforts sometimes seem pointless. What I miss the most in my everyday work is the ability to simply make everyone understand that without a representative sample, none of the investment in time, money or resources for either primary sampling, sample preparation or analysis is worthwhile. So with this lack of tools my colleagues and I started looking around the world to find ways to learn more about TOS and practical sampling to gain the ability to spread the understanding on the necessity of representative primary sampling.

After some research and participation in a basic TOS-course in South Africa, we learnt about WCSB. When reading information and articles from previous conferences we realised that this was one of the things we had been looking for. I have just started in the field of sampling so to get the opportunity to participate in WCSB6 in Lima was quite an eye-opener. To understand that the world sampling community indeed comes across the same questions and skepticism that we do, and to start to learn about how to motivate good sampling, was both interesting and uplifting. As a fairly new professional, still having quite limited experience from practical sampling problems—and especially with TOS, the possibility to participate in both a short course in TOS and to listen to the many oral presentations, was inspiring and it gave me the possibility to start to develop my own TOS knowledge systematically. The experience and expertise from leading TOS researchers and consultants was very inspiring to listen to, although at the same time, a relatively low participation from other engineers working in the process industry was a bit disappointing. WCSB would be able to be an even more comprehensive conference if more presentations came directly from the mining and processing industries, discussing real life sampling problems and solutions. To be able to network, not only with leading researchers and consultants, but also other industry professionals would be an amazing opportunity for everyone facing the challenges of sampling every day at work.

Even if I missed hearing more presentations directly connected with industry sampling problems, I left the WCSB6 with a significantly improved understanding, inspiration and some new practical approaches

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Blast hole drilling in Svappavaara, one of the more interesting sampling situations we face at LKAB today.

Illusory reconciliation: compensation of manual sampling errors

Thammiris Mohamad El Hajj,[a] Ana Carolina Chieregati[a] and Luiz Eduardo Campos Pignatari[b]
[a]**Department of Mining and Petroleum Engineering, University of São Paulo, Brazil**
[b]**Yamana Gold Inc., São Paulo, Brazil**

In the mining industry, reconciliation can be defined as the practice of comparing the tonnage and average grade of ore predicted by the geological models with the tonnage and grade generated by the processing or metallurgical plant. This practice is of increasing importance, since, if correctly executed, it allows the reliability of short-term planning to be improved and the mining and processing operations to be optimised. However, the usefulness of reconciliation relies strongly on the quality of the input data, which is generated by many different sampling methods across the industry. In fact, successful reconciliation can be *illusory*—errors generated at one point of the process can be offset by errors generated at other points, resulting in *apparently* excellent reconciliation. Such a situation will in fact also hide compensating biases in the system that will, unavoidably, surface some other day. When this happens, sampling errors are masked and may lead to an erroneous appreciation of the reconciliation system as a whole, which results in serious consequences for the mine operation, especially when reaching poorer or more heterogeneous areas of the deposit. Since valid estimation is only possible with TOS-correct sampling practices, the reliability of reconciliation results depends critically on the representativeness of the samples that generated them. This contribution a summary of an analysis of the manual sampling practices carried out at a copper and gold mine in Goias, and proposes a more reliable sampling method for reconciliation purposes. Results show that the apparently excellent reconciliation between the mine and the plant was in fact illusory; here a consequence of accidental compensation of many errors due to sampling practices for short-term planning.

Methodology

Sampling at Maraca mine

The data required to perform the undertaking reported in this work was collected during an extensive sampling campaign conducted on February of 2011 at Maraca mine in Goias, central-west of Brazil.

Short-term sampling performed at Maraca is *manual* and uses particulate material (chips) from the Furukawa model HCR1500 drill rig, which generates two products: one of fine material (back discharge) and the other of medium and coarse material (front discharge). From the front discharge pile, 12 increments are taken in radial directions, and from the back pile one increment is taken, in total generating a 13 increments composite sample.

Block sampling campaign and sampling preparation procedures

The main sampling grid of the block sampling campaign had a 10×10m size and all holes in the sampling grid were drilled with 5m depth, except the central hole with 10m depth. As presented in the following, four lithological domains were studied, with a focus on the ANX (amphibole shale), the most complex and diverse in the deposit, i.e. the critical lithological domain.

The sampling campaign was performed with two different drilling rigs, Atlas Copco L8 ROC and Furukawa HCR 1500, in order to evaluate the sampling performance of each, which employs different drill diameters. The ROC L8, drilling with a larger diameter and, consequently, resulting in larger sample masses, was *a priori* expected to generate more representative samples. The ROC L8 was used to drill the central hole; the other holes were drilled by the Furukawa. The central holes had 10m depth and were sampled every 2.5m. In the ANX domain, an extra twin hole was diamond drilled next to the ROC L8 and the Furukawa holes (and the cores analysed every 2.5m) in order to evaluate the sampling error related to the two different drillers.

After selecting the area to be sampled, the survey department marked out the hole, and each hole generated two samples, A and B. The first sample (Sample A) was collected using the standard procedure of manual sampling with a shovel, Figure 1.

Figure 1. Shovel used for manual sampling.

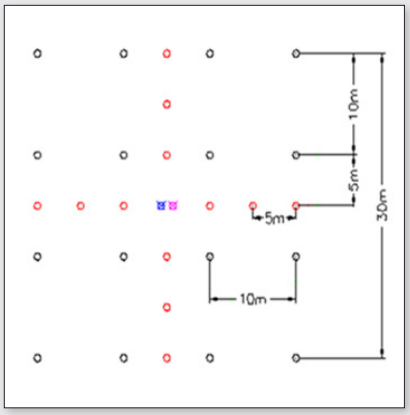

Figure 2. Sampling grid for the campaign.

After collecting Sample A (about 10 kg), *all* the remaining material (approximately 190 kg of medium, coarse and fine material) was collected, mixed well ("homogenised") and split using a proper riffle splitter to form Sample B. All samples were bagged and identified, subsequently passing through exactly the same process in the laboratory.

Sample preparation comprised crushing the 10–20 kg samples so that 95% passing 2 mm, then splitting and pulverising the 400 g sub-samples, 95% passing 150 # (or 105 µm). Next, 150 g of the pulverised material was selected and sent to the chemical laboratory for gold, copper, sulphur and iron analysis. To determine the gold content, the standard fire assay technique was performed.

Figure 3. Atlas Copco ROC L8 drill rig.

It is important to emphasise that, in order to prevent contamination and to optimise the material recovery, before starting the drill hole, the area around each hole was cleaned, especially removing all coarse material with a hoe. In this type of sampling, the most significant problem is the loss of fines. To minimise this problem, the area around each hole was covered with a canvas big enough to collect all the material recovered by the drill rig.

Summary of results and discussion

The four lithological domains studied were: (1) GNS (gneiss): stone grey, brittle, coarse grained, schist, composed mainly of biotite and feldspar; (2) BTO (biotite schist) rock dark grey, medium to coarse, with pronounced foliation, composed of biotite, feldspar and quartz; (3) QSRT/GNS (quartz sericite schist/gneiss): rock of greyish white, medium to coarse, schist, with quartz, sericite, biotite and feldspar; (4) ANX (amphibole shale): grained rock with schistosity undeveloped comprising amphibole crystals (60%) of green, oriented in the matrix formed by quartz and feldspar. The relative errors below refer to the differences generated by collecting the 13 increment composite sample (Sample A) in relation to the more representative Sample B (reference

Figure 4. Furukawa drill rig.

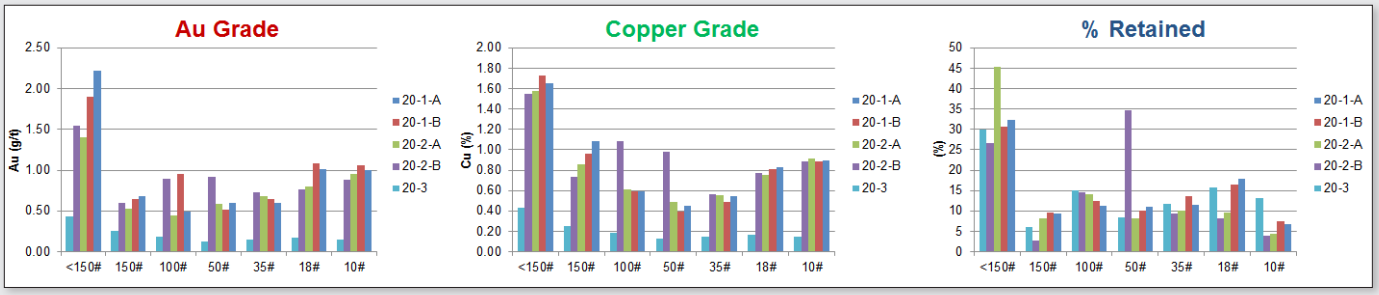

Figure 5. Gold and copper content by particle size fraction and percentage retained by particle size fraction. A and B samples as described in text. According to the Maraca Mine field sampling team, sample 20-3 originates from a part of the experimental block with distinctly lower ore grades, emphasising large fluctuations in the different regions of the block studied; sample 20-3 is therefore not immediately comparable to samples 20-1 and 20-2.

sample). Mean elative errors were: GNS—0.29%, BTO—4.71%, QSRT/GNS—3.59%, ANX—7.69%. Standard deviation (relative errors) were: GNS 43.36%, BTO 20.33%, QSRT/GNS 18.76%, ANX 10.07%.

Based on the results, the following comments can be made: (1) with the exception of the ANX domain, there is no significant systematic error (bias) between Sample A and Sample B, since the average error only varies from –0.29% to –4.71%; this means that the Samples A are practically identical to the B samples; (2) in the case of ANX domain, there is a significant bias (–7.69%) between Sample A and Sample B; this result means that, for this domain, the 13 increment *manual* samples are not accurate, presenting values 7.69% lower than the values of the reference samples; and (3) it can be noted that, for all domains, the average sampling error is negative, which means that the sample collected by the manual shovel tends to underestimate the real gold content of the material recovered by the drill rig.

The ANX domain

The ANX geological domain is comprised of weak schistose and medium grained green amphibole-quartz-feldspar rock. This domain is considered the most complex and heterogeneous of the deposit and this reason led the authors to select this domain for a special experiment using a diamond drill. Samples of 2.5 m were generated by the Furukawa, the ROC L8 and the diamond drill rig on the ANX domain. The holes were made close to each other and the drill was used as a reference to analyse the results.

Results show that both the Furukawa and the ROC L8 *overestimate* the gold and copper grades when considering the diamond drill samples as references. The Furukawa overestimates the gold grade at 75.5% and the copper grade at 32.4% (relative deviations); the ROC L8 overestimates the gold grade at 34.8% and the copper grade at 14.2%.

Conclusions

These empirical results demonstrate that a successful reconciliation can in fact be illusory. In this case study, errors introduced by manual sampling using a shovel were compensated by errors introduced by the supposedly superior drill rigs used for reference sampling. The manual 13 increments composite samples tend to *underestimate* the grades of the hole, especially in the case of gold, while the drill rig results tend to *overestimate* the grades of the hole, resulting in apparent satisfactory, but artificial reconciliations.

The manual sampling procedure in Maraca mine is therefore unsuitable for reconciliation purposes. The economic impacts of this incorrect procedure cannot be understated, because the errors inherent to the sampling process are, in this case, masked, which may well result in erroneous appreciation of the mine operation performance, especially when mining reaches poorer or more heterogeneous regions of the deposit.

It was observed that estimation errors due to the composite sampling are not as large as the errors due to the type of drill rig used. To minimise this problem, it is recommended to employ automated sampling systems with reverse circulation, which has several advantages that can far outweigh their capital outlay costs. According to Pitard,[1] some of these advantages are: (1) absence of sub-drill, avoiding the delimitation error; (2) possibility to drill several benches at the same time; (3) possibility to drill at a chosen angle; (4) minimisation of contamination and losses; (5) ability to drill into benches away from blasting; (6) sampling does not interfere in the production; (7) more precise and accurate grade control. Among the disadvantages of introducing an automated sampling system, the extra cost will always be noted by mining management and financial officers, as will the increase mine traffic involved.

Such a system was recently implemented in the Maraca mine and promptly proved to generate more precise, more accurate and, therefore, more fit-for-purpose samples, ensuring significantly increased reliability on the reconciliation results.

This study demonstrates the critical importance of sampling representativeness in all of mine the reconciliation undertakings.

Reference

1. F.F. Pitard, “Blasthole sampling for grade control—the many problems and solutions”, in *Sampling 2008*. AusIMM Publication series No 4/2008, 27–29 May 2008, Perth, p. 15–22 (2008). ISBN 978-1-920806-81-1

Thammiris El Hajj is a PhD student at the Polytechnical Faculty, University of Sao Paulo, Brazil

Opinion: "Cotton is cotton, don't worry about sampling—just look at the data..."

Claudia Paoletti
GMO Unit, European Food Safety Authority (EFSA), Parma, Italy. E-mail: claudia.paoletti@efsa.europa.eu, http://www.efsa.europa.eu

At a recent collaborative session Claudi Paoletti expressed a long-standing frustration as to the reaction she has met with in the food, feed and commodities fields. An immediate invitation to air this frustration followed from the editor of *TOS forum*—et voila!

Some 15 years ago, when I asked for clarifications on how the plants I was assessing had been selected I was simply told: *"Cotton is cotton, don't worry about sampling—Just look at the data"*. One would wish this was a singular occasion, but I have spent many years in my professional life hearing the same thing over and over again: maize is maize, soybean is soybean... a kernel is a kernel... a seed is a seed: just look at the data (don't worry about all this sampling)". However, this clashed with everything I have ever been taught and studied: by definition, the process of sampling is always a source of error in itself when estimating population characteristics and when characterising heterogeneous lots. The Theory of Sampling (TOS) was developed specifically to define suitable strategies for obtaining reliable estimates from limited numbers of measurements, minimising the unavoidable sampling error. How was it possible that apparently *nobody* was worried about sampling when the focus was on obtaining those few cotton, soybean, maize plants/seeds from which I was presumed to make inferences of general relevance? A mystery!

Years later, in 2004, I decided to attend WCSB 2 in Perth, Australia. There I discovered that there were many scientists (prominently engineers, geologists and industry managers in the mining sectors) who were also worrying about sampling—who kindly introduced me to the Theory of Sampling (TOS), which started to shed some clarity on the many questions I had. Finally I was not alone anymore: indeed searching for diamonds in rocks, sediments and soils could not be so different from searching for defect kernels in a 60,000 tons shipment!

This boosted my motivation and when back in Europe I decided to carefully investigate standard sampling procedures for agricultural commodities. Several national and international organisations have developed and recommended approaches for kernel sampling (i.e. seeds and grains), including: the International Seed Testing Association (ISTA), the United States Department of Agriculture/Grain Inspection, Packers & Stockyards Administration (USDA/GIPSA), the *Comité Européen de Normalisation* (CEN), the WHO/FAO *Codex Alimentarius*, and the International Organization for Standardization (ISO).

The vast majority of the world's recommended sampling plans are based upon the fundamental *assumption* of a "random distribution" of the parameter of interest, so that the mean, the standard deviation of the mean and both the producer and consumer risks can be easily estimated according to the Binomial, the Poisson or the hypergeometric distribution. Nonetheless, assuming randomness without justification is very risky, if not completely wrong, as it has been demonstrated in specific cases. Experience shows that such "perfect disorder" in agricultural commodities is the exception, while partial order (i.e. strong irregular heterogeneity, spatially as well as compositionally) is rather the rule.

Industrial activities are operations narrowly defined and structured in time and space. This generates correlations that, among other consequences, promote segregation during transportation and handling of the material. In addition to the inherent heterogeneity in a population of natural units, e.g. a lot of particulate material (kernels), there is *always* also an amount of induced heterogeneity—for me it is therefore clear that assuming a random distribution is an irrational wish, not supported by empirical evidence. This convenient attitude simply encourages faulty solutions to sampling problems, overlooking the issue of heterogeneity. Experimental confirmation comes from several studies investigating the degree of heterogeneity for several traits in large seed lots. Extensive heterogeneity has also been reported for kernel lots produced with large-scale facilities, such as those for grass seed production in the

Figure 1. The perennial issue in science, technology and industry: grab sampling (because the lot *appears* to be homogenous). The worst approach to sampling ever!

mid-west US. A disturbing explanation was offered by some authors "*such seed lots are seldom if ever blended by state-of-the-art equipment, but are simply conditioned, bagged, and marketed*".

Sporadic attempts to adapt the mathematical properties of the Poisson distribution to events of non-random material distributions have been made in the past, but such approaches may well violate inherent assumptions (e.g. normal variance characteristics) required for the use of such tools and have not been pursued further.

Clearly, providing recommendations for sampling approaches suitable for agricultural commodities continues to be a challenge. On the one hand, a high likelihood of non-random distribution of contaminations in most market products must be expected. On the other, there is a lack of experimental data regarding the distribution of contaminants in the world's many different products. Yet, we know from TOS that the distribution of a contaminant in a bulk greatly affects the effectiveness of sampling procedures, indeed it may fatally dismiss any chance for representative sampling at all. It is clear, contrary to today's *status quo*, that an approach free of the constraint implicit in the assumption of random distribution is unavoidable.

A number of factors must be taken into account when defining sampling protocols. Among these, the definition of a maximum acceptable sampling error is of utmost importance. The degree of risk that both the consumer and the producer are prepared to accept in terms of getting a wrong result, will contribute to the definition of this maximum level threshold. Once this is fixed, the sampling protocol can be designed accordingly, so that the costs of a sampling survey can be minimised without compromising the reliability of the final analytical results beyond a certain level (the accepted risk).

Nevertheless, when sampling is executed to check for compliance with legislation requirements (i.e. regulatory sampling) it is of crucial importance to ensure a high degree of confidence that the survey is accurate (unbiased) and that the compound sampling error is as small as indeed possible, within specified economic and workload reasons. Specifically, if there is a legal threshold limit set for acceptance of the presence of a specific contaminant, all adopted sampling protocols must ensure that such threshold is respected with the specified degree of confidence. Of course, the lower this limit is, the greater the demands will be upon the sampling plans. Extensive results from both theoretical research as well as many experimental studies show unequivocally that heterogeneity rules with respect to contaminant distribution in bulk commodities. Together, these findings pose a serious limit to unconditional acceptance of the assumption of random distribution and to the use of a simplistic Binomial distribution to estimate producer and consumer risks.

So, where do we go from here? If providing reliable sampling recommendations is a priority for the scientific community, it is necessary to invest in research projects designed to collect data on real distributions in agricultural commodities, worldwide. This would allow proper calibration of the statistical models used to estimate the degree of expected lot heterogeneity, without relying on pure unfounded *speculations*.

Meanwhile, some precautions should be taken now. As raw materials often come from different suppliers and given that industrial operations are structured in space and time, we must expect that a vestige of the original chronological order will always present in the spatial heterogeneity of any lot. Under this assumption, a systematic sampling approach is to be preferred over a random one.

As far as the number of increments used to produce the bulk sample (the composite sample) is concerned, it is very difficult to make clear, general recommendations because the number of increments required to minimise the sampling error, according to some pre-defined expectation, will depend entirely on the effective heterogeneity of the lot under investigation. The severe lack of data on the expected distributions of real lots makes it impossible to establish objective *criteria* to broadly address this problem.

Unfortunately, representative sampling is often completely uncorrelated with sampling costs: a representative protocol will have a high cost in terms of both time and financial resources necessary to carry out the necessary sampling operation. Nevertheless, excuses to perform incorrect sampling can never be justified by time and money limitations. If the sampling process is not representative, there is no reason to carry out any sampling at all—the resulting analytical results will be fatally unreliable, because of the lack of acceptable evidence regarding the uncompromised field-to-aliquot pathway. These issues have been treated in full detail elsewhere.[1–3]

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Claudia Paoletti, PhD is deputy head of the GMO Unit at the European Food Safety Authority (EFSA), Parma, Italy.

The Aloha Sampler™: concept, objective, design and implementation

Charles Ramsey
EnviroStat, Inc., PO Box 636, Fort Collins, CO 80522, USA. E-mail: chuck@envirostat.org

The *Aloha Sampler* is an innovative new sampling tool to effectively collect and combine increments from dynamic, liquid, one-phase and two-phase systems. It is extremely inexpensive and very cost effective to implement and produces more representative samples than any other conventional techniques. *TOS forum* has asked EnviroStat to present the *Aloha Sampler* for its readers.

Background

The Theory of Sampling (TOS) provides a comprehensive approach to representative sampling. Sampling tools are an important component of designing reliable sampling protocols; optimal sample mass and the appropriate number of increments for a composite sample will not provide a representative sampling if the tools are incorrectly designed or utilised. It has been estimated that 75% of all sampling tools are incorrectly designed with the result that: "enormous research is mandatory in order to develop correct sampling systems for monitoring the environment".[1] Correct sampling tools must enable an equi-probabilistic selection of all particles (molecules) at the randomly chosen increment location. Another important role of correct sampling tools is the ability to "reach" into the material being sampled, thus making all the material "available." Full availability is a critical success factor to make inferences from the analytical result back to the material in question (in TOS called the lot, and called the "decision unit" in EnviroStat's approach). This criterion has been formulated as the Fundamental Sampling Principle (FSP), see, for example, DS 3077 (2013).[2]

These two aspects, sampling tool correctness and FSP, are not the only design considerations. Some other important considerations for sampling tools are:

- durability
- easy to clean or decontaminate (if the tool is not disposable)
- easy to use (eliminate operator-induced errors)
- easy to maintain
- inert (does not interact with or contaminate the sampled media)
- maintain analyte integrity (eliminate adsorption, oxidation, leaching)
- efficient to collect and combine increments (to form composite samples)

The potential list of design criteria is too large to address here in full—it is always a function of the material sampled, environmental conditions and the analyte of interest.

Sampling of surface waters

There is a lack of sampling tools that meet the requirements of TOS for sampling of surface waters. Most surface water samplers are discrete point samplers (hand-held or weighted container samplers) and are typically some type of bottle that is opened and filled at one discrete point. These include dippers, lathes, using the sample container as the sampling device, and Van Dorn/Kemmerer type (Figure 1). All of these types of samplers do not adequately address the inherent distributional heterogeneity of the lot.

Sampling of surface water is always problematic due to its dynamic nature, especially since the composition changes with respect to both time and space. Examples of dynamic systems are industrial conduits, canals, lakes, rivers and oceans. The difficulty of sampling these systems is well recognised, alas very little has been done to develop tools and techniques to better represent

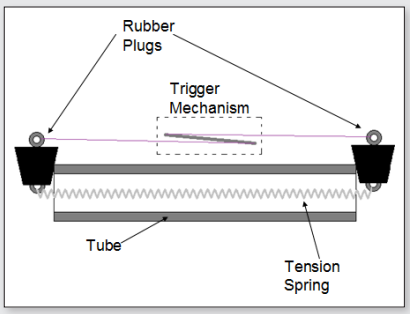

Figure 1. Generic design of Van Dorn/Kemmerer type sampler.

such dynamic systems. The New Jersey Field Sampling Manual states: "Liquids, by their aqueous nature, are a relatively easy substance to collect. Obtaining representative samples, however, is more difficult. Density, solubility, temperature, currents and a wealth of other mechanisms cause changes in the composition of a liquid with respect to both time and space. Accurate sampling must be responsive to these dynamics and reflect their actions."[3]

In one surface water study,[4] it was concluded that for individual samples drawn at 10-minute intervals (grab samples), the average variability (change in concentration between consecutive samples) was 60%—and as high as 700% for an individual result. This large variation on such a short time scale makes characterisation of surface waters virtually impossible if based on grab sampling. In the same report it was also stated that the misclassification rate of water quality was: 33%, 64% and 71% for each of three study years, respectively (% estimates are relative sampling variability (*RSV*) measures, as described in *DS 3077*).

The *Aloha Sampler* (Liquid Sampler Patent 7571657) was developed to address these concerns by an operational mode that will allow more representative liquid sampling.

The basic parts of the *Aloha Sampler* are an aperture cover (lid), and a receptacle for the liquid. The aperture cover has two holes, located along a diameter, that allow the liquid to flow into the receptacle when the sampler is submerged into liquid (Figures 2 and 3). The placement and size of holes allow for an approximate one minute fill rate if the holes are vertically aligned. If the Aloha Sampler is rotated slightly the fill rate increases to approximately two minutes. This gives the

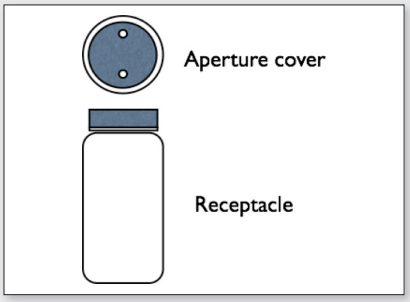

Figure 2. *Aloha Sampler* side and top view (Liquid Sampler Patent 7571657).

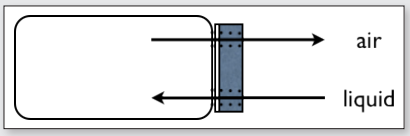

Figure 3. Basic operation of *Aloha Sampler* (Liquid Sampler Patent 7571657).

sampler flexibility to control the rate of liquid uptake.

The *Aloha Sampler* can be used in a continuous mode (sampler not removed from the liquid during sampling) (Figure 4), or non-continuous/intermittent mode (sampler removed from the liquid between increment sampling deployment locations) (Figure 5). An example of a continuous operation would be sampling from a point on the shore of a river, out ten feet from the shore, from the surface to the bottom *in one continuous motion*, never breaking the surface of the water during collection. An example of a non-continuous operation would be sampling the length of a river where the *Aloha Sampler* is inserted in and removed from the river at each increment location (partially filling receptacle at each increment location). Both modes result in a reliable sample. The *Aloha Sampler* can be used to collect spatially and/or temporally

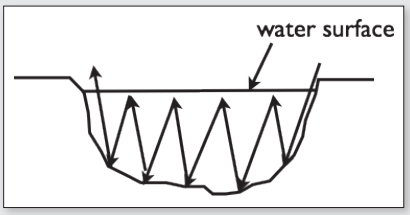

Figure 4. Continuous sampling path to represent a stream section without interrupting the sampling operation.

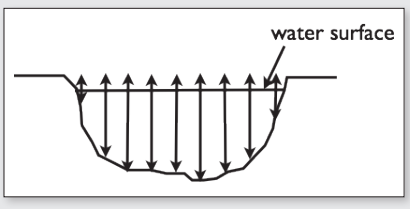

Figure 5. Collection of multiple vertical increments to form an integrated sample (composite sample).

Figure 6. The *Aloha Sampler* in operation. Note air bubble leaving the upper hole in the aperture cover.

Figure 7. Use of the *Aloha Sampler* with an extension pole.

Table 1. Lihue Mill Bridge, Kauai, Hawaii, 5 November 2013. Owen Environmental, Kalaheo, HI.

	Time	pH	Dissolved oxygen (%)	Total suspended solids ($mg\,L^{-1}$)
Rep. 1	9:11	7.07	76.0	12
Rep. 2	9:14	6.96	75.5	13
Rep. 3	9:16	6.95	75.8	12
Mean		—	75.8	12.3
RSV (%CV)			0.3	4.7

Total suspended solids by Method SM 2540 D
Dissolved oxygen and pH by YSI ProPlus Multi-parameter WQ Meter

Table 2. Lihue Mill Bridge, Kauai, Hawaii. 31 October 2013. Owen Environmental, Kalaheo, HI.

	Time	pH	Dissolved oxygen (%)	Total suspended solids ($mg\,L^{-1}$)
Rep. 1	11:11	7.07	73.9	13
Rep. 2	11:13	7.15	74.7	12
Rep. 3	11:19	7.08	72.9	14
Mean		—	73.8	13
RSV (%CV)			1.2	7.7

Total suspended solids by Method SM 2540 D
Dissolved oxygen and pH by YSI ProPlus Multi-parameter WQ Meter

integrated samples.[5] This allows great flexibility for either type of deployment. If the decision unit is small enough, a continuous sample can be easily collected. For larger decision units, a non-continuous sampling method may be desired due to the fixed filling time of the *Aloha Sampler*. Continuous sampling of liquids typically provides a more representative sample if the logistics allow integration of the entire decision unit.

To use the *Aloha Sampler*, simply submerge the device horizontally with the two holes aligned vertically (one above the other) to the desired depth of the liquid at a constant transit rate. The liquid will flow in the lower hole, and the air will escape through the upper hole (Figures 3 and 6). Once a vertically integrated increment is collected at a single location, move to the next location and take another increment etc. The transit rate, depth of liquid, fill rate and number of vertically integrated increments must be considered individually for each case, but it will always be possible to obtain a meaningful, optimised sample. Some pilot experimentation may be necessary to determine the ideal timing for specific cases—nothing could be easier, however.

The *Aloha Sampler* can also be attached to a pole to access hard to reach areas, Figure 7.

Once the sample is collected, the *Aloha Sampler* aperture cover is removed and a solid cover is placed on the sample bottle. The sample is then prepared and stored in the same way as any other type of liquid sample. The *Aloha Sampler* can be sterilised for the collection of bacteria.

The *Aloha Sampler* has been used in Hawaii to collect data from construction activities to determine impact to nearby streams. Multiple samples (replicate sampling) were collected for a specific project to determine the *reproducibility* of the Aloha sampling approach. *RSV* (%CV) is quite satisfactorily low for this type of sample collection (Table 1 and 2). These samples were collected using the *Aloha Sampler* on a pole (Figure 7).

Conclusion

The *Aloha Sampler* is a promising new tool to effectively collect and combine increments in a dynamic liquid system, producing highly flexible, problem dependent samples with very low sampling variability. It is extremely inexpensive in fixed capital outlay and very cost effective to implement and use. The *Aloha Sampler* produces fit-for-purpose samples over a wide range of hitherto difficult-to-sample lot and decision units. The *Aloha Sampler* is a significant improvement over commonly used sampling approaches and equipment targeting surface waters in a wide range of situations.

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Chuck Ramsey is the founder of the company EnviroStat, Inc. (www.envirostat.org). EnviroStat provides specialised training in the areas of field (bulk) sampling, laboratory subsampling, statistics and quality control. EnviroStat's approach integrates all facets of sample plan design, implementation and data interpretation. EnviroStat's methodology has been used by various state and federal government agencies as well as private industry for over 20 years to improve sample representativeness and defensible decisions.

A review of sampling and monitoring protocols related to radioactive elements in fractured rock aquifers

Gathier Mahed
Bioresources Engineering Research Group, Faculty of Applied Sciences, Cape Peninsula University of Technology, Cape Town 8000, South Africa. E-mail: gaathier@gmail.com

An analysis of current available sampling and monitoring protocols related to radioactivity has been undertaken. The international best practice is outlined in order to better understand the available sampling as well as monitoring protocols related to radioactivity. Thereafter, the most relevant South African groundwater sampling and monitoring protocols are examined for their application to the subject matter. This piece of work highlights the need for more sampling and monitoring protocols related to fractured rock media in general and radioactivity in fractured rock media in particular.

Introduction

Groundwater monitoring can be defined as the scientifically-designed, continuing measurement and observation of the groundwater situation.[1] Ideally the design of network density and sampling frequency would be based on an optimisation of the cost of monitoring and of the accuracy of collected and derived data related to the objectives of the network.[2] In line with this, Netili *et al.* further propose that groundwater monitoring and sampling sites should be selected to be representative of geographic distribution, geology, groundwater use, land use and groundwater flow regimes, amongst other factors.[3]

Thus we can see that, ideally, the sampling programme for a groundwater investigation will collect the minimum number of samples required to have adequate three-dimensional spatial and stratigraphic coverage of the area being investigated. So, the fundamental task is to obtain samples that are representative, diagnostic and characteristic of the aquifer and to analyse them with minimal change in composition.[2] The data stemming from this knowledge should in turn lead to better groundwater management practices.

To effectively monitor and assess the radioactivity of uranium and its daughter elements in the groundwater, concentration analysis is often employed in the laboratory. This method requires appropriate *in situ* groundwater sampling, which can be influenced by device, selection of sampling network, quality and quantity of water sampled etc. Unfortunately, there is not yet a uniform groundwater sampling guideline which can be applied to the areas dominated by fractured rocks. Particularly, a single sampling manual and monitoring protocol is not available for the research of radioactive elements in fractured rocks.[1]

Background

Radioactivity sampling has normally been conducted in a similar fashion to sampling for heavy metals.[4] Fetter[5] argues that some of these radioactive elements behave in a similar manner to these heavy metals. Therefore it is justified to extract water samples utilising the same methodology.

In most cases a known area with uranium mineralisation is targeted for sampling. Thereafter, liaison with the laboratory is done in order to determine the volumes of sample required for analysis as well as the reagents, bottle types and storage and transport methods required in order to maintain sample integrity. Furthermore, initial work prior to sampling also includes the analysis of previous work completed in the area in order to determine the available data, data quality, gaps in data and well location amongst other factors. One of the most important factors is the nature of the sub-surface media, which will also be determined from desktop studies.

In primary porous media one is able to use multiple sampling methods due to the relatively uniform nature of the aquifer material. These methods include, but are not limited to:

- bailer (elongated plastic cylinder with a ball valve for containing the sample);
- groundwater pump (this could be attached or a mobile device);
- depth specific sampler (bailer with a control valve at the surface);
- windmill (at the end pipe a sample is normally taken).

Cook[6] has shown that, in fractured media, the spatial variability as well as the hydraulic conductivity can vary substantially. This is due to the fact that the fractures are isolated and not necessarily always water bearing or even interconnected (Figure 1).This poses problems for aquifer characterisation as well as groundwater sampling. Durrani and Ilic[7] have also stated that radioactive elements precipitate on fracture walls. The elements which precipitate depend on the pH, Eh as well as temperature of the groundwater, as shown by Ilani *et al.*[8] This means that spatial and temporal variability of radioactive elements in fractured rock aquifers is evident.[7] This poses an added complication to sampling for radioactivity in fractured rock media due to the temporal and spatial variability of the elements of interest in the groundwater sample.

Methodology

An online search was conducted for sampling and monitoring protocols developed all over the world. This search was then further refined in order to only include those manuals examining radioactivity and heavy metals. These manuals were intensively studied and the evolution of the sampling science within this specific field also analysed. Case studies related to sampling of radioactive elements in fractured rock media were also studied. These provided insights into applicable sampling methodologies and external factors to examine. These were all compared and best practice was examined for the specific application.

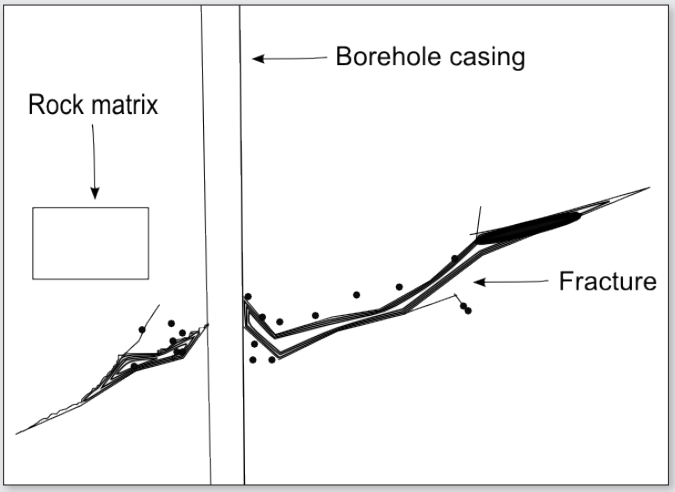

Figure 1. A typical example of a well intersecting a fracture, with alterations in the immediate vicinity of the fracture indicated by circular filled dots.

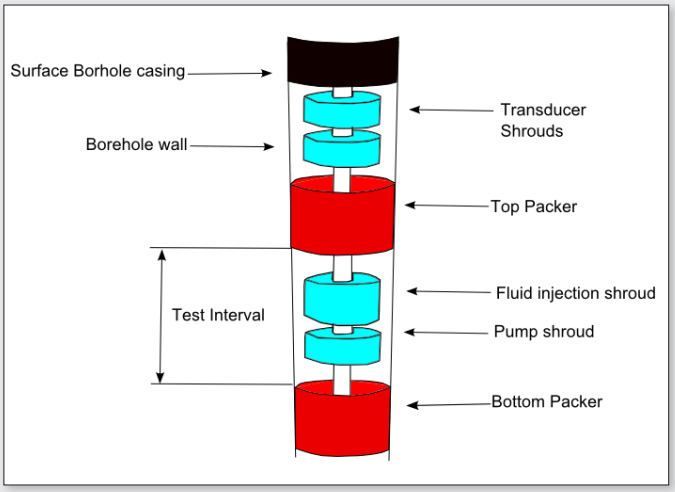

Figure 2. Multifunction BAT[3] in a bedrock borehole with borehole packers inflated to seal against the borehole wall (adapted from Reference 13).

International perspective

Jousma and Roelofson[1] have reviewed approximately 400 documents relating to sampling and monitoring groundwater and related aspects. The authors have not found a single document relating to radioactivity sampling in fractured rock aquifers. Furthermore, it was recommended that more research in hard rock aquifers is required.[1]

Despite the aforementioned point, the IAEA[9] have developed a manual specifically for radioactive monitoring of near surface waste facilities. Unfortunately, the manual does not deal with the intricacies of sampling, but instead refers the reader to various other manuals. One of these manuals was most probably the first groundwater sampling manual and was developed by Barcelona *et al.*[10] This document outlines a specific route to follow when sampling:

- the device should be simple to operate to minimise the possibility of operator error;
- the device should be rugged, portable, cleanable and repairable in the field;
- the device should have good flow controllability to permit low flow rates (=100 mL min^{-1}) for sampling volatile chemical constituents, as well as high flow rates (>1 L min^{-1}) for large-volume samples and for purging stored water from monitoring wells;
- the mechanism should minimise the physical and chemical disturbance of groundwater solution composition in order to avoid bias or imprecision in analytical results.

Freyer *et al.*[11] concur with the aforementioned recommendations. The authors have also shown that the low flow sampling devices, which are used for radon sampling, do not greatly affect the radon concentration. The low flow sampling devices used in this study were a membrane pump, a submersible pump and a bailer for purposes of comparing the effect of various instruments on degassing. Therefore, these devices are all aptly suited for sampling and fit the criteria previously mentioned by Barcelona *et al.*[10]

Furthermore, Barcelona *et al.*[10] systematically outline a general sampling protocol which could be used for any analyte which may be of major concern. The steps, goals and recommendations are shown in a tabular format in order to minimise confusion and simply explain the specifics relating to each systematic step (Table 1).

The EPA[12] also penned a protocol in a similar fashion to that of Barcelona *et al.*[10] The greatest attention was afforded to the physical aspects of groundwater flow and monitoring well design. Interestingly enough the use of packers is advocated in order to isolate a specific area of interest within the sub-surface.[12] These inflatable devices are placed above and below the fracture of interest, in order to isolate the area (Figure 2). Prior to this a pump is isolated within the structure. Shapiro[13] has designed the BAT3 (Bedrock Aquifer Transportable Testing Tool) specifically for sampling in fractured rock aquifers. Besides having packers and a pump it is also installed with three pressure transducers. One is located above the packers, one between the packers and the last is below the packers. These are utilised in order to monitor fluid pressure and correctly ensure that the packers are properly isolating the fracture of interest.[13]

Puls and Barcelona[14] strongly recommend that low flow sampling, in conjunction with packers, should be done in fractured rock aquifers. This approach should only be attempted after identifying the water bearing fractures and thus the sampling zone can be isolated.

EPA[12] promotes the hourly sampling of fractured aquifers for field determinands. This protocol was developed specifically for nuclear waste facilities and the parameters which would be measured on an hourly basis would include those which a data logger could determine. These include temperature, TDS and water level. This would aid in determining whether leakage has occurred from the storage facility, and also aid in determining anomalous inflows of contaminants in groundwater in a natural setting. The aforementioned could be inferred from a fluctuation in TDS, pH and temperature. It is an effective monitoring strategy and the aforementioned parameters would act as indicators for the contamination of groundwater.

OHIO EPA[15] have also developed a document specifically for groundwater sampling and monitoring. Once again there is not much difference between this technical manual and that of Barcelona *et al.*[10] and EPA.[12] An interesting component is the description of the use of statistics in order to assimilate data into information. Helsel

Table 1. Generalised groundwater sampling protocol (adapted from Reference 10).

Step	Goal	Recommendations
Hydrologic measurements	Establishment of static water level	Measure water level to approximately 0.3 cm (0.01 ft)
Well purging	Removal of stagnant water which would otherwise bias representative sample	Pump water until well purging parameters (e.g. pH, T, Eh) stabilise to approximately 10% over at least two successive well volumes pumped
Sample collection	Collection of samples at land surface and or in well-bore with minimal disturbance of sample chemistry	Pumping rates should be limited about 100 mL min^{-1} for volatile organics and gas sensitive parameters
Filtration/preservation	Filtration permits determination of soluble constituents and is a form of preservation. It should be done in the field as soon as possible after collection	Filter trace metals, inorganic anions/cations. Do not filter: TOC, TOX, volatile organic compound samples. Filter other organic compounds samples only when required
Field determinands	Field analysis of samples will effectively avoid bias in determination for parameters/constituents which do not store well, e.g. gases, alkalinity, pH etc.	Samples for determination of gases, alkalinity and pH should be analysed in the field if it all possible
Field blanks	These blanks and standards will permit the correction of analytical results for changes which may occur after sample collection, preservation and storage	At least one blank and one standard for each sensitive parameter should be made in the field on each day of sampling. Spiked samples are also recommended for good QA/QC
Sample storage	Refrigeration and protection of samples should minimise the chemical alteration of samples prior to analysis	Observe maximum sample holding or storage periods recommended by the Agency. Documentation of actual holding periods should be carefully performed

and Hirsch[16] have also shown the importance of utilising statistics as a tool for the interpretation of data. The document acts as a reference tool for hydrologists in the USGS and provides the basic, as well as advanced, statistical methods applicable to the hydrological sciences.[16]

OHIO EPA[17] have made the concerted effort to update their document, unlike Barcelona *et al.*[10] and EPA.[12] Specific chapters have been modified and/or added in order to make the manual more relevant. An extensive examination of sampling methodology was revisited and could prove to be useful, especially for the novice, due to its simplicity and applicability. Unfortunately, radioactivity is not focused upon and thus sampling protocol for radioactive elements is not covered. This must be due to the fact that OHIO EPA[17] was heading for a more generic sampling methodology and nothing specific was included in this updated version.

The USACE[18] has developed an engineering and design manual entitled *Monitoring Well Design, Installation, and Documentation at Hazardous, Toxic and Radioactive Waste Sites*. The manual unfortunately does not cover aspects of groundwater sampling. Once again this is not in line with the purpose of the document. Instead the purpose of the engineer manual is to provide the minimum elements for consideration in the design, installation and documentation of monitoring well placement and other geotechnical activities at projects known or suspected to contain chemically hazardous, toxic and/or radioactive waste.[18]

Wilde *et al.*,[4] on the other hand, have turned some attention towards the sampling of radioactivity. They suggest that radioactive elements should be sampled in a similar manner to heavy metals. This is a view shared by Weaver *et al.*[19] as well as Smedley *et al.*[20] Wilde *et al.*[4] suggest that a 1-litre polyethylene bottle be acid rinsed and then the sample should be preserved to pH < 2 using HNO_3. It would also mean filtering the sample in order to remove suspended particles which could possibly lead to the precipitation of metals onto its surface. This manual is a major step forward, in terms of radioactivity sampling. We also find that each chapter of the manual is published separately and updated on a periodic basis.[4] Furthermore, corrections are posted on the website and these additions should be made to the respective chapters. This USGS manual is also quite generic and provides methods for surface as well as groundwater sampling.

Yeskis and Zavala[21] tackled methods of sampling as well as equipment and recommend low flow sampling, just like Puls and Barcelona.[14] This approach is justified because samples with elevated levels of turbidity are collected by high speed pumping. This results in the inclusion of otherwise immobile particles which cause an overestimation of specific analytes of interest.[14] Furthermore, with regards to radioactivity, we find that once there is a change in chemical environment there is also an alteration in the dominant radionuclide in the aqueous phase.[8] A good example of this is the fact that uranium dominates under oxidising conditions whereas radium prefers a reducing environment.[22] Thus Yeskis and Zavala[21] also advocate filtering, in order to differentiate between dissolved and non-dissolved species, therefore eliminating adsorbed radioactive particles.

DOE[23] as well as IAEA[9] developed a monitoring protocol for radioactive waste facilities. Aspects of monitoring network design, well placement and data management

Table 2. Comparison between sampling manuals and their relevance to radioactivity sampling. X—indicates that the topic is covered in the document; a blank cell shows that the topic was omitted from the document.

Reference	General sampling protocol	General sampling methods	General sample treatment	Monitoring protocol	Monitoring well design	Sampling frequency	Radioactivity sampling
4	X	X	X				X
9				X			X
10	X	X	X		X	X	
12	X	X			X	X	
15	X	X	X		X		
18		X			X	X	
19	X	X	X				X
21	X	X	X				
23				X			
24				X		X	

are examined.[23] IAEA[9] instead look at the monitoring of general environmental conditions, which includes soil, air, hydrology and hydrogeology. Both manuals are geared towards facilities management and DOE[23] provides a good systematic monitoring protocol. IAEA[9] on the other hand make many references to various other documents and is not as user friendly as DOE.[23]

Thus we see the natural progression of sampling manuals. This evolution involved a step towards the intensive examination of the physico–chemical parameters, as shown by Weaver *et al.*[19] Furthermore, we find specific manuals becoming all-encompassing guides and thus the need to constantly update as the knowledge base is widened, as in the case of Wilde *et al.*[4] and OHIO EPA.[15] It can also be seen that certain manuals, such as Jousma's guideline[24] on groundwater monitoring for general reference purposes, are very specific in their subject matter. Therefore, a simple comparison of the manuals examined in this review has been completed (Table 2). This was based on headings or sections in the document. Therefore if no section or subsection on the topic was present then the topic was regarded to be insufficiently covered or omitted.

A South African perspective

The most comprehensive groundwater sampling guide in South Africa at the moment is the second edition of *Groundwater Sampling*.[19] This manual outlines every aspect of sampling and even highlights what could go wrong. It is a practical approach to sampling and gives the user a systematic check list for field sampling.

Weaver *et al.*[19] have shown that prior to sampling it is necessary to liaise with the laboratory in order to ascertain which containers, preservatives and reagents are to be used when sampling for radionuclides. Levin,[25] who also developed a local sampling manual, states that sample bottles should be thoroughly rinsed with 10% HCl and then emptied and rinsed thrice with deionised water. Levin also states that the samples should be taken as follows:[25]

- 2 L for the determination of the trace elements such as Al, As, Be, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Ti, Si, Zn;
- 500 mL for the determination of U, V and NO_3^-;
- 250 mL for the determination of the major components SO_4^{2-}, Cl^-, F^-, Na^+, K^+, Ca^{2+} and Mg^{2+}.

These aforementioned authors definitely took cognisance of the fact that the trace metal content of water could be altered in storage. Therefore, the use of acid has been recommended in order to reduce the possibility of precipitation of heavy metals, which includes radioactive elements. Taking cognisance of the fact that radioactive elements are heavy metals one then has to filter the sample, once it has been extracted from the aquifer.[25] Typically a 0.45 µm filter paper is utilised. Levin also suggests that the filter paper should be kept, if the suspended particles are to be analysed.[25] This is important, taking into consideration that radium precipitates under oxidising conditions.[8] Other than these specific methods, relating to sampling for radioactivity, we find that all other aspects are completely generic within these two locally developed manuals.

Weaver *et al.* advise that approximately two well volumes should be purged in order to remove stagnant water.[19] Levin on the other hand says that the pump should be run for 10 minutes before a sample is taken.[25] Prior to this a water level should be measured. Furthermore, it is suggested that field parameters be measured *in situ*.[19,25] These include temperature, total dissolved solutes, electrical conductivity, pH, Eh and oxidation reduction potential. This is done for the following reasons:[19]

- to check the efficiency of purging;
- to obtain reliable values of those determinands that will change in the bottles during transport to the laboratory;
- to obtain some values that may be needed to decide on the procedure or sampling sequence immediately during the sampling run.

Weaver *et al.* also advise the use of a flow-through cell in order to maintain the *in situ* condition of the sample and thus gain an actual representation of the conditions in the sub-surface.[19]

Vogel *et al.* were visionary in their use of packers for sampling in the Beaufort West area.[26] Even though their study is not strictly classified as a protocol, it is interesting to take note of the methods used. A submersible pump mounted between two inflatable rubber packers, approximately 1.8 m apart was utilised.[26] This equipment allowed

multi-level sampling within boreholes. At the depth of interest the packers were inflated with nitrogen and the pump then delivered water to the surface from the aforementioned fracture.

Future outlook

Unfortunately, there is not yet a uniform groundwater sampling guideline which can be applied to areas dominated by fractured rocks. Particularly, no single sampling manual and monitoring protocol is available for the effective sampling of radioactive elements in fractured rocks.[1] Xu *et al.* have recently developed a pre-cursor to such a document,[27] specifically for a South African context in fractured rock aquifers. This protocol formed part of a larger study funded by the Water Research Commission (WRC) of South Africa related to uranium in groundwater.

In the interim, the use of the same sampling protocol as for heavy metals has been employed in most instances. This is common due to the nature of the radioisotopes being similar to heavy metals.[5]

Case studies such as Yucca Mountain in North America as well as the Nagra project in the Swiss Alps are good examples of multi- and interdisciplinary work in order to understand fractured rock aquifers and the unsaturated fractured zone. These are not manuals or protocols in the strictest sense of the definition according to Jousma.[24] They do, however, provide a blueprint for similar studies in order for a complete site characterisation and an understanding of sub-surface processes at various scales.

Further research is required as well as the large scale implementation of the developed protocol in order to ascertain the applicability thereof. Thus the continued understanding of hard rock aquifers could be fostered. This is of the utmost importance if the scientific community is to continue to advance and solve problems such as water supply from these saturated geological units.

The data stemming from the studies should be put to good use and aid in the development of an effective monitoring programme. It is useless if the data is not utilised to its maximum capacity.[2] This can only be done if statistical analysis is brought into play. Also an effective database management system would be needed in order to maximise the use of data.

One major factor which needs to be included in future sampling manuals is the contextualisation of the work within the framework of the Theory of Sampling (TOS). It seems as if most major works have merely just looked at best practice in line with the latest knowledge of the contaminant to be sampled. These manuals have not included the science of sampling or looked at aspects of representative, unbiased sampling, as outlined by Petersen *et al.*[28] This is especially true in water science as hydrologists are infamous for grab samples. Furthermore, the fact that measurement uncertainty needs to be further examined will aid in alleviating issues around data quality.

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Dr Gaathier Mahed is currently an independent groundwater consultant. He has a passion for research and is a guest lecturer at multiple institutions. He currently resides in Cape Town, South Africa.

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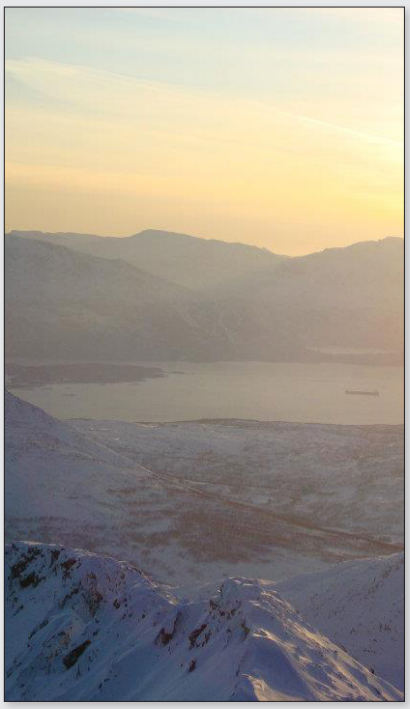

A cape size vessel with LKAB Iron ore leaving Narvik harbour in Norway (as seen from ski-touring to the peak of Nonstinden).

continued from page 6

to be able to better handle the sampling problems that I face daily. It also gave me the incentive to learn more about TOS and how this can help us to collect representative samples and improve our quality control throughout the entire processing chain. In some parts of the process I do believe that LKAB have a vast amount of experience and are well aware of the need for representative sampling. While in other stages of the process we are falling behind and still have a long way to go to reach a situation with representative primary sampling. This means that the knowledge of TOS is very much needed, not only for us working with designing primary sampling every day, but for everyone working with and around the sampling situations and managers at all levels.

I look forward to WCSB7 in Bordeaux in 2015—and I hope to see more quality and process engineers and other sampling professionals from industry both attending and presenting at this important conference.

After graduating with a MSc in Quality Technology and Management at Luleå University of Technology, the decision to start my career within the mining industry in the north of Sweden was an easy one. To be able to combine a career in the expanding mining industry in Sweden with the possibility to spend all my spare time in the mountains to go skiing, rock climbing, mountain biking and trail running is the perfect life for me. Since I started at LKAB in 2010, I have been working within Method Development in Quality Control, with a main focus on sampling and measurement uncertainty.

Sampling conferences galore—what do attendees take home?

Kim H. Esbensen, Editor

Spurred by an ever increasing number of sampling conferences on both hemispheres, at the recent Sampling 2014 the editor made a grab sampling of opinions targeting two major exhibiting companies and one academic dignitary. To the extent that no grab sample can ever be representative, *TOS forum*'s readers are encouraged to complement with individual comments, reflected views and further opinions…

Sampling 2014—What does academia get from Sampling and WCSB conference(s)?

Dick Minnitt
Wits University, Johannesburg, South Africa

The attraction of the "Sampling" conferences for academia lies principally in the opportunity it provides to remain in the flow of what is happening in the world of the "sampling" fraternity. The last conference theme, "Sampling—Where it all begins" was, as with other events organised by the AusIMM and CSIRO, to the point and catchy.

Assessments

Conferences organised and arranged by professional bodies, such as the AusIMM, naturally have their member's interests at heart and on seeing the call for papers one's immediate reaction is: Is the research I have done in the past year or two worth reporting to my peer group? The importance of a conference such as Sampling 2014 to the academic is that it is essential to remain involved by contributing meaningful research. Involvement in the annual round of conferences, including the World Conferences on Sampling and Blending (WCSB series) and the AusIMM-CSIRO sampling conference held every other year, is part of the routine for academics. Once you are in the loop, so to speak, and have presented at one conference, the immediate thought is: "What aspects of current research should be covered at the next conference" or "How can I extend my current area of research". Attendance at the next conference requires commitment and dedication and they bring forth meaningful research that would otherwise remain unreported. A particular advantage of the sampling conferences is that the spectrum of research opportunities across the sampling, bed blending, statistical process control, QA/QC and equipment development fields is wide.

The immediate reaction to an event such as we have enjoyed at Sampling 2014 is that it is very professionally run. The quality of the presentations demonstrates that presenters are dedicated to improving our understanding of all manner of sampling issues. In addition, the support and spread of international delegates demonstrates that people from most of the world (less South America) understand the importance of sampling to the quality and texture of the decisions that can be made when good sampling is undertaken. A very significant factor is that basic principles and the underlying probabilistic concept that "each and every fragment must have the same opportunity as every other fragment of being in the sample" is consistently kept at the forefront of all of the deliberations at sampling conferences. This, together with a number of other basic principles featured, is aimed at ensuring that good sampling practice and principles are carried out in the wider industry.

Apart from the round of friendly equipment suppliers who are always ready to explain the advantages and benefits of their particular brand of sampling equipment, the conference also becomes a showcase for some very clever inventions. The importance of the basic theoretical principles being in place is that the leading manufacturers of sampling equipment have also engaged themselves with the process, and are keen to make sure that equipment they produce obeys and upholds these basic principles. The nature of the competitive market is such that different equipment manufacturers will have a sharp eye out for their neighbours' latest developments and advancements.

The academic world is said to live by the precept "publish or perish". This may be true to some extent, but there are in fact a fair number of academics who publish because they really have something that is worth informing industry and the sampling fraternity about. The value of sitting for three days and listening to a very broad range of speakers is that it provides a rich bed of areas for *additional* research themes to one's own—particularly when the research is driven by curiosity. In addition, it provides an opportunity to earth one's ideas and concepts in the critical minds of those whose interests are mainly related to providing a service to industry and have to make a living around issues related to sampling. This means that by presenting (and publishing) ideas that arise in academia, whose principal concern

is to educate and investigate, one is pushed out of one's comfort zone into the rough and tumble of life where individual consultants are struggling to make a living, as are the companies involved a.o. The current setup of sampling conferences, in which one can find at least one every year (this may, or may not, be a little too much) is a vital melting pot for the entire sampling community, serving its needs well.

Conclusion

The role and importance of communications amongst those interested and committed to the sampling conferences, between conference events, cannot be over emphasised. In this regard the *TOS forum* serves a particularly important role as it provides a vehicle for contributions and notes that would not normally appear as a publication or in conference proceedings. In addition it provides a forum in which ideas can be debated and considered amongst members of the sampling community in a manner that allows for differences of opinion to be aired and appreciated.

Dick Minnitt graduated from Wits University in geology in 1974 (MSc thesis was awarded the Corstiphine Medal). In 1979 he completed a PhD dealing with aspects of the Hiab porphyry copper system in Southern Namibia, the world's oldest know porphyry system. After a brief period at Anglo American Corp. he joined Spectral Africa, a subsidiary of JCI. From 1981 until 1995 he ran a private consultancy working in Namibia, Zimbabwe, Mozambique and Bolivia. Having completed a second Masters in Mining Engineering in 1993, he joined the School of Mining Engineering at Wits University in 1995, where he currently holds the JCI Chair of Mineral Resources and Reserves, teaching statistical valuation and geostatistical evaluation of mineral deposits (undergraduate level) and is responsible for courses in the Theory and Practice of Sampling, Grade Control, Mineral Economics and Minerals Marketing (postgraduate level).

Sampling 2014—an industry perspective

FLSmidth, Automation—Process and Quality Control
Welshpool DC, WA, Australia. www.flsmidth.com

AusIMM's series of Sampling conferences are recognised as a premier forum for presenting a great variety of topics related to the practical and operational aspects of sampling. These conferences are testimony to the need for ongoing scientific discussion on all issues related to sampling. The first three Australian Sampling conferences formed the foundation for ongoing debate amongst sampling practitioners and produced publications of a high standard.

The success of these conferences is, in part, due to sponsorship from those involved in the sampling industry. FLSmidth is committed to supporting the sampling fraternity through ongoing sponsorship of major sampling conferences. Essa Australia, and now FLSmidth, was a principal sponsor of the past three international World Conferences on Sampling and Blending (WCSB) and also the major sponsor of the AusIMM's Sampling 2008, Sampling 2010 and Sampling 2012 conferences in Perth. We continue this support through the major sponsorship of Sampling 2014. The sponsorship of Sampling 2014 under the FLSmidth banner is an opportunity to provide customers with an insight to the FLSmidth "One Source" capabilities. In addition to offering customers with solutions for sampling projects there are opportunities to present FLSmidth's competences in other disciplines such as laboratory automation, materials handling and control systems.

Conferences of this calibre help improve the level of understanding of the theory and practice of sampling, encourage best practice and allow an exchange of ideas associated with the Theory of Sampling (TOS) and its practical application. FLSmidth strives to engineer samplers and control systems that meet or exceed international standards. These samplers are complemented by a comprehensive range of size reduction and laboratory sample preparation equipment. It is only natural then that we actively support these world leading fora.

Ken Potts, Sampling Design Specialist:

"What I get out of an event like Sampling 2014 is a different perspective on my working world. It is a good opportunity to see sampling through the eyes of a geologist or a statistician or a chemist. This perspective helps me design better machines so these professionals can keep their businesses running profitably."

Craig Adams, Senior Technical Advisor:

"2014 was my first Sampling conference and was an eye opener to learn of the rich and passionate history of Sampling. Also to see the zeal of metallurgists, chemists and geologists, and how they strive to determine the true quality of their beloved processes. The conference was re-assuring in that our integrated ISO sample station control software is well aligned with the thinking of the others within the Sampling profession."

Richard Daubney, Mechanical Sampling Designer:

"By attending Sampling 2014, I received a better—more in depth—level of understanding of all the various sampling methods. I received insight into both the theory and the practical aspects of these methods.

It was also wonderful to put faces to names from all around the globe. One can't truly grasp the magnitude of all that is involved in sampling as a whole until you attend a conference like this... It was a very interesting and insightful experience!"

Ian Clark, General Manager Automation:

"As a company we support Sampling 2014 as we did for previous AusIMM Sampling conferences as we see it as a great meeting place for industry and technologists to debate and share their expertise. This makes sense for both the scientific and industrial partners and we believe it creates value with benefit for all."

Tore Thoen Neidel, Engineering Manager:

"An event like Sampling 2014 is important as it puts emphasis on this relatively narrow part of the scope of plant operation, a narrow part with high potential for process and financial impact compared to the capital cost. Sampling is thus an area that easily loses focus in many projects. By bringing a wide global expertise into the same room, as was the case again for Sampling 2014, and adding the daily users and vendors as well, generates a great environment to nurture the understanding of the importance of sampling. It further broadens the knowledge of people already in the sampling community at the same time as it draws new members for the field. My personal highlights, apart from presenting the latest work we have produced, was some of the client application cases as well as news from the frontline—where the technology is leading us"

Matthew Cook, Sales Manager, Australia:

"We have very few opportunities to get closer to many of our sampling customers and potential clients in one location. Events like Sampling 2014 allow FLSmidth to discuss new ideas and technologies with experienced and knowledgeable professionals within this specialised area."

Sampling 2014—A manufacturer's perspective

Rolf Steinhaus, director, and Multotec colleagues

The biennial conference "Sampling 2014" was held on 29–30 July at the Pan Pacific Hotel, Perth, close to well established mining industry head offices and associated project companies in this city capital of Western Australia. This event was jointly organised by the Australasian Institute of Mining and Metallurgy (AusIMM) and CSIRO. Sampling 2014 follows on from the highly successful previous events (initiated in 2008, 2010 and 2012). Multotec, as an aligned manufacturer, see this as a must-be-there event. This conference is also conveniently held in alternate years with respect to the World Conference of Sampling and Blending (WCSB) conferences (initiated in 2003 in Denmark). Multotec has been asked to assess the value of this conference for an OEM manufacturer.

Conference assessment

Sampling 2014 was a great opportunity of bringing together like minded people all having some stake in ensuring quality is achieved in all aspects of sampling, metallurgical accounting and QA/QC in the mining and minerals industry in particular and to a lesser degree, other industries. The event again brought together professionals from many varied disciplines including geologists, engineers, metallurgists, grade controllers, chemists, sampling consultants, specialists and managers involved in all aspects of sampling mineral streams and commodities from exploration, resource estimation and mine development through to process control, quality control and final mineral exports. The attendance figures (188 participants) tell a very clear message: there was a modest international contingent of 22, with the remainder of participants being from Australia. Foreign attendance was made up of six proudly South Africans (three of them presenting), i.e. Multotec (3), Wits University (1), University of Pretoria (1) and AMS (1). Other international attendees were from USA (3), France (3), Canada (2), Finland (2), Kenya (1), Ghana (1), PNG (1), United Kingdom (1), Denmark (1) and Germany (1). The majority of the foreign contingent also regularly attends the international WCSB conferences, so there are many similarities in terms of the conference organisation and content. It was interesting to see that there were no visitors present from South America or Asia, possibly due to language barriers; their presence was clearly missed. There were some 22 exhibitors all told with booths related to sampling and preparation, on-line analysis, laboratory equipment and robotics, accreditation authorities as well as mining equipment and technology suppliers.

The sampling conference theme on this occasion was: "Sampling—Where it all begins" which highlights that despite advanced and leading edge technologies available in the minerals industry, correct extraction of samples for resource development, process control and plant optimisation is very often still neglected and misunderstood. This is a recurring and necessary message from these forums—to ensure that sampling "correctness" is upheld. More attention, continuing education and spending needs to be allocated to proper sampling, sampling preparation and analysis on the geological and mineral process front to ensure that samples are representative—because sampling is, indeed: where it all begins!

Many key business decisions in industry are being based on poor sampling practices!

A conference of this calibre improves and enhances the level of understanding of the theory and practice of sampling (TOS) by key speakers, i.e. Francis Pitard, Dominique Francois-Bongarcon, Professor Kim Esbensen, Dr Geoff Lyman, Dr Ralph Holmes; all leading luminaries. This event has reinforced consistently, since 2003, the sampling theory of Pierre Gy (TOS) by reiterating its comprehensive and relevant approach.

Client presentations were of a very good standard, with themes covered: drill and blast hole sampling, sampling theory, plant automated sampling (with a comprehensive

paper on the Cape Lambert Port B ship loading sampling and analysis facility). Papers on new developments in sampling equipment design, case studies and metallurgical accounting ensured the full range of sampling aspects were covered for the mining and minerals industry. There are many opportunities to branch out into other areas whether food, pharmaceuticals, agricultural, environmental etc. where identical sampling issues abound. The sharing of experience with visitors via presentations, or during the important breaks, helped further improve the understanding and hence accepted compliance to what is correct sampling practice. It was indeed good to see how we can learn from each other as we each focus on our areas of responsibility. The paper on mass-based versus time-based sampling scenarios in iron ore (an ongoing question for many) shed good light on the subject.

The lack of attendance by project houses was disappointing, however, and this was not a singular event, sadly. Project house process and mechanical engineers are key stakeholders in ensuring that final sampling solutions are effective and reliable, as they are often responsible for interfacing sampler equipment designs with new or existing plant—this goal is in reality not as often achieved, however. This is an unfortunate international trend as project houses pursue lowest cost procurement agendas. We need to find ways to bridge this gap between the sampling community conferences/exhibitions and project houses for the benefit of all involved parties.

Multotec

Multotec participated at the AusIMM 2014 as a conference sponsor and with a standard booth—and, as always, was trying to provide a fresh look! The stand layout, with a shelf working surface, was in particular appreciated during the lunch breaks, and we found ourselves hosting very many visitors, which depleted our sweet bowl contents rapidly, but improved networking opportunities and communication reciprocally.

As an OEM manufacturer, like others, all trying to align themselves with TOS and the challenges that go with that, a conference presentation was also on the agenda, on a new pressurised pipe sampler for slurries intended to provide a better solution than what exists currently. We all need to combat current non-compliant devices to avoid misleading and biased results. We

are consistently aiming to achieve sampling correctness via designs and TOS-compliant protocols to clients. Equipment designs are never perfect, but we need strive to approximate to the desired standard as much as possible in practise. A sneak-preview of some of our initial developments was shown and we embraced subsequent constructive critique to improve our initial designs further.

Company assessment

Some stand visitors, both existing and new clients or contacts, expressed significant interest in our products and offerings. Exhibitors, in general, are exposed to far more potential clients or partners in a short period of time at these events, and need to make time count. Apart from networking opportunities with visitors, we were also able to gather information on the status of international sampling activities and to discuss new advances and developments on equipment with the sampling fraternity—and even with some of our competitors. Sampling 2014 was indeed a successful conference in cementing our alliances internationally and hopefully becoming better known and more visible as a discerning mineral sampling equipment and solution provider. For some in our team, it was their first trip to Australia, a memorable experience of Perth's city centre, the Australian culture and people. The highlight is finally meeting clients in person, after the very many e-mails and telecoms over the years, and to be able to put a face to previous communication. As a final point, manufacturers really appreciate dealing with the academic delegates and with knowledgeable end users and customers. Clients can be very specific about what they want from their suppliers when sampling matters are discussed. The international WCSB conferences and the dedicated southern hemisphere conferences are a great success for all parties involved, commercial, academic, companies... See you at the next conference!

A simpler system of dimensions and units: part 2

Francis F. Pitard

In Part 1 (*TOS forum* 1/2) it was demonstrated that **time** and **mass** are relative concepts originating in the human imagination and it was postulated that they do not necessarily require units of their own. This constitutes but the tip of the iceberg, however, intended to furnish a simple start for the reader. Here the enquiry into a simpler system of dimensions and units continues deeper this time aiming at showing how worrisome the paradigm behind contemporary science is.

Electromagnetic quantities: eliminating the necessity of permeability and permittivity units of their own

The electrostatic dimensions of electric charge or quantity of electricity, Q, in the MLT system are:

$$[Q]=\frac{L^{1/2}\cdot M^{1/2}\cdot k^{1/2}}{T} \quad (1)$$

or

$$[Q]=\left[\frac{\sqrt{L\cdot M\cdot k}}{T}\right] \quad (2)$$

It is necessary to add electric permittivity, k to the dimensional statement. Magnetic statement of the dimensions of Q requires the use of magnetic permeability, u, instead of k.

In the magnetic system,

$$[Q]=\left[\sqrt{\frac{L\cdot M}{u}}\right] \quad (3)$$

It is well established that the product $k\cdot u$ is numerically equal to $1/c^2$, where c is the velocity of light, so that:

$$[k\cdot u]=\left[\frac{1}{c^2}\right]=\left[\frac{T^2}{L^2}\right] \quad (4)$$

In solving the problem of the height of liquid beads, earlier, we showed how to transfer from a MLT system to a $LP\rho$ system. The reason for this exercise may now appear clear. Changing from $MLTk\cdot u$ to $LP\rho$ enables us to eliminate k and u from the dimensional formula for the quantity of electricity and all electromagnetic quantities!

This is huge progress; again it becomes obvious time and mass do not need units of their own as they are relative concepts depending on other far more fundamental factors. It was also an easy way to demonstrate the relativity of time and mass.

Conversion of time, T, to the $LP\rho$ system gives

$$[T^2]=\left[\frac{L^2\cdot\rho}{P}\right],$$

therefore:

$$\left[\frac{1}{c^2}\right]=\left[\frac{T^2}{L^2}\right]=\left[\frac{L^2\cdot\rho}{P\cdot L^2}\right]=[k\cdot u]=\left[\frac{\rho}{P}\right] \quad (5)$$

A note on the value of $k\cdot u$ is in order. Long before the relation $k\cdot u=1/c^2$ was established theoretically, it was observed to be true to the limits of measurements of the three quantities. It is also true that one may assign any dimension and any value to either k or u, provided the relation $k\cdot u=1/c^2$ is numerically and dimensionally satisfied. There should, therefore, be no objection not only to

$$[k\cdot u]=\left[\frac{T^2}{L^2}\right]=\left[\frac{\rho}{P}\right], \text{ but also to } [k]=\left[\frac{1}{P}\right]$$

and $[u]=[\rho]$.

We may now convert electromagnetic quantities from $MLTk\cdot u$ to LPD using:

$$[M]=[\rho\cdot L^3],\ [T^2]=\left[\frac{\rho\cdot L^2}{P}\right],$$

$$[k]=\left[\frac{1}{P}\right],\ [u]=[\rho]$$

Then, the quantity of electricity, Q is:

$$[Q]=\left[\frac{L^{\frac{3}{2}}\cdot M^{\frac{1}{2}}\cdot k^{\frac{1}{2}}}{T}\right]$$
$$=\left[L^{\frac{3}{2}}\cdot\rho^{\frac{1}{2}}\cdot L^{\frac{3}{2}}\cdot P^{\frac{-1}{2}}\cdot\rho^{\frac{-1}{2}}\cdot L^{-1}\cdot P^{\frac{1}{2}}\right]=[L^2] \quad (6)$$

or

$$[Q]=\left[L^{\frac{1}{2}}\cdot M^{\frac{1}{2}}\cdot u^{\frac{-1}{2}}\right]=\left[L^{\frac{1}{2}}\cdot\rho^{\frac{1}{2}}\cdot L^{\frac{3}{2}}\cdot\rho^{\frac{-1}{2}}\right]=[L^2] \quad (7)$$

The Potential Difference, E is:

$$[E]=\left[\frac{L^{\frac{1}{2}}\cdot M^{\frac{1}{2}}}{\sqrt{T\cdot k}}\right]$$
$$=\left[L^{\frac{1}{2}}\cdot\rho^{\frac{1}{2}}\cdot L^{\frac{3}{2}}\cdot P^{\frac{1}{2}}\cdot\rho^{\frac{-1}{2}}\cdot L^{-1}\cdot P^{\frac{1}{2}}\right]=[P\cdot L] \quad (8)$$

or

$$[E]=\left[L^{\frac{3}{2}}\cdot M^{\frac{1}{2}}\cdot T^{-2}\cdot u^{\frac{1}{2}}\right]$$
$$=\left[L^{\frac{3}{2}}\cdot\rho^{\frac{1}{2}}\cdot L^{\frac{3}{2}}\cdot P\cdot\rho^{-1}\cdot L^{-2}\cdot\rho^{\frac{1}{2}}\right]=[P\cdot L] \quad (9)$$

The product $Q\cdot E$ should, of course, have the dimensions of energy:

$$[Q\cdot E]=[P\cdot L^3]=[L^{-1}\cdot M\cdot T^{-2}\cdot L^3]=\left[\frac{M\cdot L^2}{T^2}\right] \quad (10)$$

The $LP\rho$ system may be improved by noting that the dimensions of velocity are:

$$\left[\frac{L}{T}\right]=\left[\frac{P^{1/2}}{\rho^{1/2}}\right] \quad (11)$$

and introducing a dimensional quantity, C, to replace, for convenience only, the otherwise clumsy L/T expression for velocity. We then have a $LP\rho C$ system. Some $LP\rho C$ dimensions of electromagnetic quantities follow.

Magnetic Field Strength, H:

$$[H]=[C] \quad (12)$$

Electric Current, I:

$$[I]=[L\cdot C] \quad (13)$$

Electric Resistance, *R*:

$$[R]=[\rho\cdot C] \tag{14}$$

Electric Inductance, $(E\cdot T)/I$:

$$\left[\frac{E\cdot T}{I}\right]=[\rho\cdot L]=[R\cdot T] \tag{15}$$

Magnetic Moment:

$$[L^3\cdot C\cdot\rho] \tag{16}$$

Electric Moment:

$$[Q\cdot L]=[L^3] \tag{17}$$

The *LPρC* system eliminates fractional exponents in dimensional expressions, provides a clear perception of the meaning of *k* and *u*, and simplifies dimensional operations in the "electromagnetic" system.

Solving an electromagnetic dimensional problem using both the *MLTk·u* and *LPρC* systems is instructive.

Problem: Find the magnetic field strength at distance, *d*, from a magnet of length much less than this distance and with a magnetic moment, *m*. Table 2 shows the needed characteristics.

$$H=f(m,d,u)=c\cdot m^x\cdot d^y\cdot u^z \tag{18}$$

In *MLTu* terms,

$$\left[\frac{\sqrt{M}}{\sqrt{L\cdot T^2\cdot u}}\right]=\left[\frac{\sqrt{L^5\cdot M\cdot u}}{T}\right]^x\cdot[L]^y\cdot[u]^z \tag{19}$$

$$\frac{1}{2}=\frac{x}{2},\ -\frac{1}{2}=\frac{5x}{2}+y,\qquad -1=-x,\ -\frac{1}{2}=z+\frac{x}{2} \tag{20}$$

In *LPDC* terms,

$$[C]=[L^3\cdot\rho\cdot C]^x\cdot[L]^y\cdot[\rho]^z \tag{21}$$

$$1=x,\ 0=3x+y,\ 0=x+z \tag{22}$$

In either case,

$$x=1,\ y=-3,\ z=-1 \tag{23}$$

$$H=c\left[\frac{m}{u\cdot d^3}\right] \tag{24}$$

The constant *c* must be determined otherwise. If *p* is on the magnetic axis, $c=2$; if on the magnet's equatorial plane, $c=1$.

Evidently, the *LPρC* approach is simpler. More importantly, **it removes the barrier that has existed between dynamical and electromagnetic units**. The reason for this is that the "dimensionally independent base units" of the *SI* system **are not dimensionally independent** as falsely claimed**.** Conversion to the *LPρC* system demonstrates this. Note that *LMTu* yields four equations for only three unknowns.

Table 1. Comparison between *LMTku* and *LPρC*.

Physical quantity	Symbol	Dimensions LMTku	Dimensions LPDC
Magnetic field at p	*H*	$\left[\frac{\sqrt{M}}{\sqrt{L\cdot T^2\cdot u}}\right]$	[*C*]
Magnetic moment of magnet	*m*	$\frac{\sqrt{L^5\cdot M\cdot u}}{T}$	$[L^3\cdot\rho\cdot C]$
Distance from magnet	*d*	[*L*]	[*L*]
Magnetic permeability	*u*	[*u*]	[ρ]

Thermal quantities

There seems to have been no serious attempt to weld thermal and mechanical dynamics into a single discipline. In the *MLT* part of the *SI* system, there is no mention of temperature. Thermodynamics makes no mention of time; its reasoning and the equations that express it use pressure, volume and temperature, *P*, *V*, *T*. The *SI* system, for obvious reasons, uses the symbol *K* for thermodynamic temperature, and this symbol is used here to replace the thermodynamic *T*, and also all kinetic symbols that have been used to represent temperature. The thermodynamic volume, *V* is rejected in favour of L^3, or $[V]=[L^3]$. As mentioned at the very beginning of this series, **the first step toward unification is a common language**! The discovery that $[k]=[1/P]$ and $[u]=[\rho]$ **has united electromagnetic and dynamics**. There must be a way to include thermodynamics, thermionics and kinetics in the scheme.

Incorporation of thermal quantities in the existing scheme will not be easy. Fundamental adjustments will have to be made; basic opinions and beliefs must be altered, if not completely overturned. In this attempt, we intuitively, or otherwise, guess that the proper dimensions of temperature are

$$[K]=[L^3\cdot C^2]=\left[\frac{L^3\cdot P}{\rho}\right]$$

in the *LPρC* system, and therefore

$$\left[\frac{L^5}{T^2}\right]$$

in the *LMT* system.

Before dealing directly with thermal problems, it is well to recall the *SI* (2011–2012) definitions of the units in which the "**seven dimensionally independent quantities**" are measured.

Metre: the path length travelled by light in vacuum during a time interval of 1/299,792,458 of a second.

Kilogram: The mass of the international kilogram prototype.

Second: the duration of 9,192,631,770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.

Ampere: The constant current which, if maintained in two straight parallel conductors of negligible cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force of 2×10^{-7} Newton per metre length.

Kelvin: The fraction 1/273.16 of the thermodynamic temperature at the triple point of water.

Mole: the amount of substance in a system which contains as many elementary entities as there are atoms in 0.012 kg of carbon 12.

Candela: the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} Hz and that has a radiant intensity in that direction of 1/683 W per steradian.

The symbols for these units are: m, kg, s, A, K, mol, cd, respectively.

These rather erudite definitions were designed to correct difficulties with original definitions of these quantities arising from the ever-increasing precision and accuracy of measurements. This does not remove the "King Henry's Thumb" nature of the original definitions, on which those written above are based. To unite the dynamic, electromagnetic and thermodynamic systems will require careful consideration of all these original definitions.

This will require revision of some favourite axioms.

The *SI* unitary system is based on properties of our earth. This may be better than a system based on King Henry's dimensions, but it is still arbitrary and hardly more fundamental!

There is a clear relation between kilogram, metre and second, and even a vague relation between these and temperature. The metre is a fraction of the earth's circumference; the kilogram is a mass (originally the weight) of a cubic decimetre of water, and thus is related to the kilometre and the earth's mass through the gravitational constant. The second is 1/86,000 of a solar day, and hence is related to the earth–sun distance in kilometres. The degree Kelvin is 1/100 of the difference in temperature of boiling and freezing water at 0.760 m of mercury of ambient pressure.

These units were adequate and appropriated when the earth was the centre of the Universe; they are no longer appropriate. Dressing them up by improving their definitions does not help, only more sweeping changes will.

To establish a new unitary system requires selection of more appropriate units of length, mass, time, electric current, temperature, amount of substance and luminous intensity. On the way, it may be demonstrated that these are not all dimensionally independent, as has been demonstrated for electric charge.

As a first step, we may examine the concept of length or distance, and area, volume and content, with the intent of selecting a new unit. **The idea of using a well-established wave length is appealing, and adds the possibility of finding a new unit of time during the same exercise.**

The dimensions of length

Length, L, is a vector quantity. It is necessary to distinguish dimensionally among $[L_x]$, $[L_y]$, $[L_z]$ and possibly $[L_t]$, where x, y, z refer to three spatial directions and t refers to time. Problems in dimensional analysis often require that the vector character of length be taken into account. A simple example may illustrate the concept.

Problem: Find the rate of fall of a small sphere through a viscous fluid. In a classic experiment, Millikan made use of Stokes' solution of this problem to measure the electron charge. Table 2 lists the relevant parameters, and

Table 2. Examples of physical quantities with their dimensions.

Physical quantity	Symbol	Dimensions
Velocity of sphere	v	$\left[\frac{L_z}{T}\right]$
Density of sphere	d	$\left[\frac{M}{L_x \cdot L_y \cdot L_z}\right]$
Diameter of sphere	r	$\left[L_x^{1/2} \cdot L_y^{1/2}\right]$
Density of liquid	ρ	$\left[\frac{M}{L_x \cdot L_y \cdot L_z}\right]$
Viscosity of liquid	n	$\left[\frac{M}{L_z \cdot T}\right]$
Acceleration of gravity	g	$\left[\frac{L_z}{T^2}\right]$

$$v = f(d^x, r^y, \rho^z, n^w, g^v) \qquad (25)$$

In this case, it is not necessary to substitute $\rho \cdot L^3$ for M or L/C for T, the result is the same if this is done. The vector lengths are necessary for the solution, which is

$$v = \frac{(a_{\text{constant}}) \cdot \left[r^2 \cdot g \cdot (d - \rho)\right]}{n} \qquad (26)$$

H.E. Huntley (reference 24 in our original textbook) gives a full explanation. Vector lengths are often necessary when angles are involved. The dimensions of an angle are not simply $[L/L]$, but may be $[L_X/L_Y]$ or, in the case of light velocity, not $[L/T]$ or $[\sqrt{P}/\rho]$, but $[L_x/L_t]$.

Candidates for the role of fundamental unit of length are the classic electron radius, r_e; the first Bohr radius, a_0; the Dirac Compton wave length, λ_c; and R_∞, the Rydberg constant:

$$r_e = \alpha^2 \cdot a_0 = 2.81794092(38) \cdot 10^{-15}\,\text{m} \qquad (27)$$

$$a_0 = \frac{\alpha}{4\pi \cdot R\infty} = 0.52917720859(36) \cdot 10^{-10} \qquad (28)$$

$$\lambda_C = \frac{h}{m_e \cdot c} = 2.4263102175(33) \cdot 10^{-12}\,\text{m} \qquad (29)$$

$$R_\infty = \frac{m_e \cdot c \cdot \alpha^2}{2h} = 10973731.568527(73)\,\text{m}^{-1} \qquad (30)$$

With
fine structure constant:

$$\alpha = 7.2973525376(50) \cdot 10^{-3} \qquad (31)$$

electron mass:

$$m_e = 9.10938215(45) \cdot 10^{-31}\,\text{kg} \qquad (32)$$

light velocity:

$$c = 299792458 \text{ (exact) m s}^{-1} \qquad (33)$$

Planck's constant:

$$h = 6.62606896(33) \cdot 10^{-34}\,\text{J s}^{-1} \qquad (34)$$

Numbers in parentheses refers to significant figures that are still uncertain.

Since the dimensions of light velocity are $[L/T]$, the logical unit of velocity is $1NU[L/T]$, of length is $1NU[L]$ and of time is $1NU[L/C] = 1NU[T]$. Choosing the conversion factors $[L]$ and $[T]$ from *NU* to *SI*, or *cgs,* or still another system, depends on the choice of factors from the above listed *SI* values. The two most precisely known values are those for R_∞ and c, but until the *NU* value for R_∞ is determined, it is best to begin with a_0 and c. Benefiting from arguments not presented here (see original book), the best value for the conversion factor $[L]$ is $(2.3^2 \cdot \pi^2 \cdot \alpha^2 \cdot a_0)$ then:

$$1NU[L] = 1 \cdot (5.006151\ldots 10^{-13}) \qquad (35)$$

$$SI[\text{L}] = 5.006148\ldots 10^{-13}\,\text{m} \qquad (36)$$

The conversion factor $[T]$ for time follows at once from the velocity of light, $c = 299792458\,\text{m s}^{-1}$.

$$1NU[T] = 1NU\left[\frac{L}{c}\right] = 1.\left[\frac{L}{c}\right] \qquad (37)$$

$$SI[\text{L}] = 1.669872\ldots 10^{-21}\,\text{s} \qquad (38)$$

In what follows, values for these conversion factors are carried to seven significant figures, because nearly all are valid to that level of precision, with eventual later establishment of the individual precisions.

The dimensions of mass

The difference between mass and weight is well recognised, but the *SI* unit of mass is the kilogram, a unit of weight on the earth's surface. There is a relation between volume density and mass.

$$\rho = \left[\frac{M}{L^3}\right] \text{ or } [M] = [\rho \cdot L^3] \qquad [39]$$

A distinction is necessary between mass as a quantity of matter, the gravitational mass, M_g, and inertial mass, M_i. Numerous repetitions of Eötvos' classic experiment with various modifications of a double-armed torsion balance have established that, in any unitary system, the values of M_i and M_g are identical. Gravitational and inertial mass are different concepts, related by a conversion factor, 1.00000…

The several Eötvos experiments have established this factor to a precision of at least one part in 10^9, and there is almost no doubt that $M_i / M_g = 1$. Inertial mass differs from gravitational mass in that it is a vectorial quantity. In the $LP\rho$ system, mass has dimensions $[M] = [\rho \cdot L^3] = [\rho \cdot L_x \cdot L_y \cdot L_z]$. The inertial mass of a projectile travelling in the x direction has dimensions $[\rho \cdot L_x \cdot L_y \cdot L_z]$.

The above discussion of the dimensions of length and mass are to be viewed as preliminary to a welding of all dynamic, electromagnetic and thermal quantities into a new, single unitary and dimensional system.

The techniques of dimensional analysis have been used above to show the validity of several arguments involving electromagnetic and dynamics. In Part 3 we will apply these techniques to thermal quantities. At this stage, keep in mind that visionary statement from Charles O. Ingamells:[1]

"If someone, somewhere, on some enchanted evening long ago, had decided, intuitively or otherwise, that the proper dimensions of electric charge are $[L^2]$, Physics today would be very different."

Slowly, but surely, for the reader implications may perhaps start to emerge far away on the horizon: are particles the way we think they are? Or, could it be that we got it wrong, and that they actually are something different, far more subtle to imagine? Our enquiry continues…

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Francis Pitard, gold medal recipient from the World Conference on Sampling and Blending, combines his experience in nuclear chemistry, analytical chemistry, geochemistry, and statistical process control in consulting and auditing of many international companies and teaching short courses on sampling. He lives in Colorado, USA.

What is wrong with this sampler?

A sampling of current dictionaries for the term "sampler" reveals by far the most entries on the digital sampler, used in signal analysis or in music (see, e.g., in Wikipedia for a start…) than what is intuitively meant here related to physical sampling (or sampling using sensors, probes etc.) as used in mining, minerals extraction, process industries a.o. A diligent search reveals only a few such definitions, which all would seem to match well the TOS community's tacit understandings, however, there are still differences. Thus:

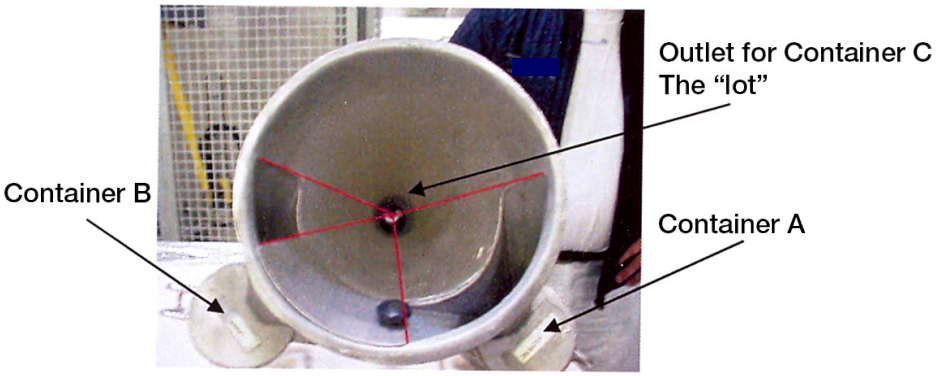
Sampler *n*. Thing that takes samples. (*The Oxford Guide to the English Language*).

Sampler *n*. A mechanical or other device designed to obtain small samples of materials for analysis; used in biology, chemistry and geology. (McGraw-Hill *Dictionary of Scientific and Technical Terms*)

Sampler *n*. One that collects, prepares, or examines samples. (*Merriam-Webster On-line Dictionary*, http://www.merriam-webster.com/dictionary/sampler)

At the outset therefore a "sampler" can be both a "thing", a mechanical or other device or a "person" ("one that collects… samples").

This is the start of a new mini-column, intended to raise the reader's interest: WHAT is WRONG with THIS sampler no. 1? The reader is encouraged to analyse the samplers presented, and to note which of TOS' sampling errors are committed. Comments and answers to ke@geus.dk.



Characteristics of sensor-based sorting technology and implementation in mining

Name of candidate: Christopher Robben
Institution/University: RWTH Aachen University, Department of Mineral Processing; Tomra Sorting Solutions/mining
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Sensor-based sorting (SBS) is a sustainable processing technology for separation of coarse particles in the size range 10–350 mm. Provided full liberation in coarse particle sizes, SBS is technically applicable for very many aggregate commodities. Through its impacts on all processes in the mineral production chain and the technical options to separate on new separation criteria at relatively low cost, SBS becomes a disruptive technology.[a] SBS is still at the market entry level for many commodities and applications, and far from reaching a technical saturation level; the sensing technology and mechanical platform developments are still developing rapidly. There is an interesting aspect of sampling in SBS, which is explored in this brief PhD summary.

Sensor-based sorting systems

Sensor-based sorting (SBS) is used as an umbrella term for all applications in which particles are detected individually by a relevant sensor technique, to be accepted or rejected by an amplified mechanical, hydraulic or pneumatic process.[1] Figures 1 and 2 display two types of sensor-based sorting equipment, the chute-type and the belt-type. In both cases up to 10,000 particles can be presented to a scanning system *per second*. This translates, depending on the particle size and weight, to a throughput of 10–300 tonnes per hour. The most commonly applied detector systems in today's industrial scale sorting systems are line-scan cameras in combination with LED and laser illumination, NIR spectrometers, UV spectrometers, Vis spectrometers, X-ray-scintillators, radiometric scintillators and AC inductive coils. All these sensor systems must deliver spectral and spatial data at very short integration periods, typically <10 ms. The data is processed in real-time, after which high-speed air jets are activated in case single particles are intended to be ejected from their normal path of flight into the so-called *eject fraction*, while all other pass into the *accept fraction*. In order to minimise energy consumption, a maximum of 50 wt% is ejected with compressed air; a higher reject fraction results in switching the eject/accept logic in the software.

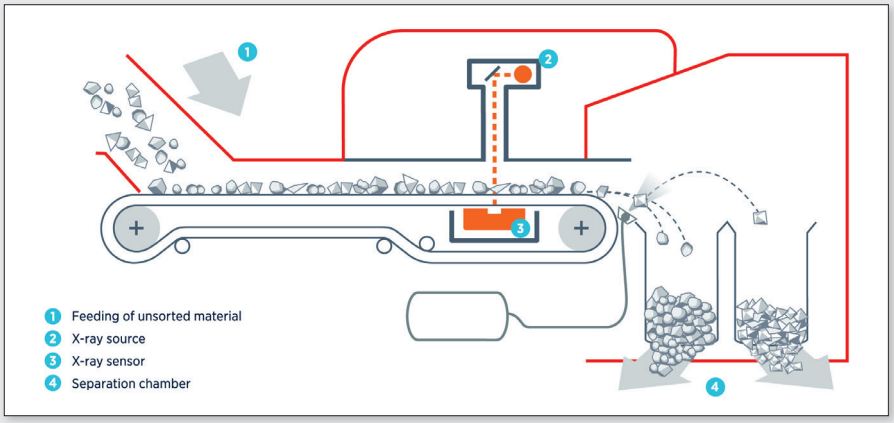

Figure 1. Working principle of belt-type X-ray transmission sensor-baser sorting (SBS) system.

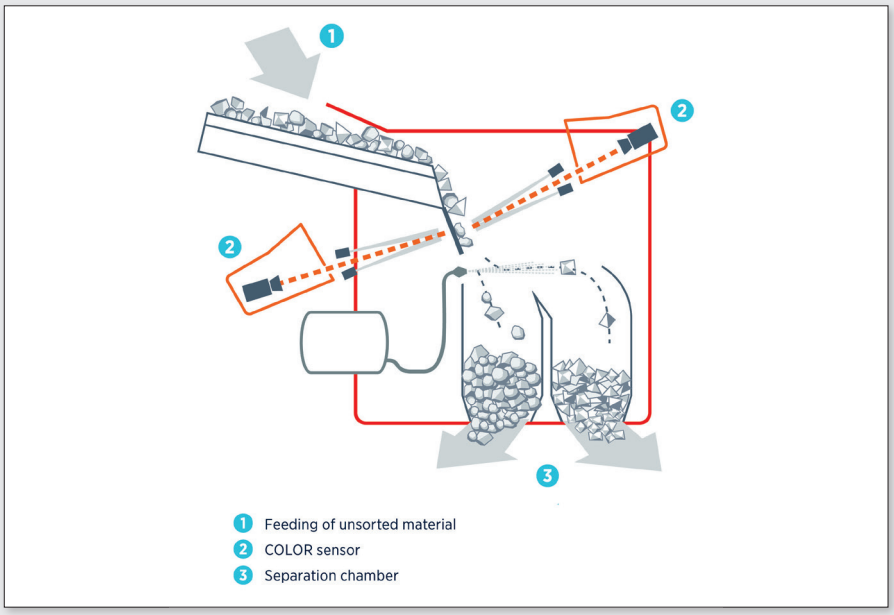

Figure 2. Working principle of chute-type colour-sorter, in this case also a transmission SBS system. Through deployment of double side scanning approx. 70% of the surface can be measured and evaluated.

[a]Technology which has a significant impact on productivity improvement and/or cost reduction and/or satisfaction of needs; also referred to as step-change innovation.

While the presently presented PhD dissertation is focussed only on mining (where the technology was originally developed in the 1930s for diamond processing), today this technology is also widely applied in the food processing and recycling industries, amongst others.

The impacts of sensor-based sorting on mineral production are discussed using technical–financial scenarios that focus and highlight characteristic effects. The main scenarios offering high economic benefit are, amongst others, sensor-based sorting installations for reduced capital expenditure for downstream plant equipment, or increased productivity through enhanced production capacities by elimination of barren waste, ore type diversion into specialised plant lines. The scenarios treated in the thesis show that sensor-based sorting not only contributes to an environmentally friendly operation through reduced resource consumption and environmental impact, but also significantly decreases production costs. The highest possible economic benefits can be achieved when maximising productivity either through increased feed grade or increased overall recovery.

The impacts of SBS on the total separation efficiency are evaluated using so-called process efficiency functions. These, in combination with the liberation function, constitute a specific four-dimensional process application characterisation, which links recovery to yield, particle size and throughput. This concept shows the full characteristics of sensor-based sorting technology, which allows future analysis of process- and sub-process-efficiency contributions to be performed for different applications. Analogous to these process characteristics, operating cost functions and capital expenditure functions specifically delineate the expenditures in dependence of yield and throughput for stationary and semi-mobile applications.

The PhD study introduces the basic components of a general sensor-based sorting plant and their respective optimality requirements. Both stationary and semi-mobile installations are evaluated and two fully developed semi-mobile plants are described. As semi-mobile installations are relatively compact they allow for flexible application at strategic logistical positions which in many cases can be closer to the mining face with obvious logistic and economic benefits. This endeavour requires careful implementation into the full mining system, especially due to the resulting backfill activities.

SBS and TOS

All investment decisions regarding SBS are made on the basis of pilot experiments or campaigns which further critical data based on sampling and laboratory test procedures. It is prudent that all new materials first are characterised with respect to their sorting feasibility. In this context, the critical issue is, of course, to base this pilot study on a documented representative primary sample of the target material, an issue that will appear trivial to readers of this publication, but may not at all be similarly obvious to clients who often want to supply the test material themselves. This issue constitute sthe first critical success factor before any technicalities regarding the SBS system itself can be meaningfully addressed.

Coarse particle SBS separation introduces significant challenges due to the magnitude of the fundamental sampling error (FSE) involved. The theory of sampling (TOS) offers a proven scientific and practical framework that must be applied in the context of all single particle tests for sensor-selection, calibration and validation and for gaining operational data. Often SBS systems operate in a process environment akin to the process analytical technology (PAT) concept, well-known from many other technological and industrial application sectors, for example Reference 2. SBS and PAT therefore encounter the same issues, for example, also with respect to data fidelity vs chemometric multivariate calibration.

Though sometimes hailed as “sampling-free” techniques, neither PAT nor SBS does in fact eliminate sampling errors. Both PAT and SBS sometimes violate TOS’ fundamental sampling principle (FSP). Depending on the working principle (reflective vs transmitive SBS) and the arrangement of the detection hardware, not all components will always have the same probability of being detected; likewise reflective technologies only observes particle surfaces. And **all** process analytical technologies must be calibrated and validated with respect to *relevant* and *reliable* reference materials/data, which in turn **must be** extracted by representative physical sampling.

The constitutional heterogeneity (CH) and the distributional heterogeneity (DH) of a given test material give an understanding of the grade variation of the lot to be processed (SBS); a proper heterogeneity characterisation is essential in order to ensure that representative training and validation sets are provided for the

Figure 3. On-site containerised, semi-mobile chute-type sorter installation.

Figure 4. Another instance of a system which, like SBS systems, in principle can sample and characterise all individual fragments (individual fish in this case)—comparatively rare occurrences in the domain of TOS.

critically important sorter calibration. But there can never be an automatic guarantee that the specific training set used will also be equally representative for all *future data sets*, for which reason proper validation of multivariate calibration models appears on the agenda.[3,4] As described in the literature, sampling, calibration and validation form a trinity in PAT and thus also SBS applications. Variographic analysis is identified as highly relevant and directly applicable for process efficiency testing and evaluation also for the case of SBS systems.[3]

A rare occasion: CH = DH

Sensor-based sorting systems transform the dimensionality of original 3-D, 2-D or 1-D lots—to a 0-dimensional body, as it is the effective total lot that is sampled (i.e. imaged). In fact, sensor-based sorting systems are intended to scan and characterises **all** single particles in the process stream (**all** lot fragments in the TOS parlance) as they appear in the cross section of the 1-D process lot. Upon reflection it becomes clear that if scanning all particles of a process stream individually can be achieved (all fragments are "sampled" with 100% efficiency), DH *vanishes*! One could alternatively say that the grouping and segregation error (GSE) is completely eliminated in properly designed, installed and maintained transmitive SBS systems. In such a case, FSE can easily be determined empirically as the difference between the nugget effect and sill in a variographic analysis of the sorter's process data—provided that the SBS system operates fully according to its design paradigm such that no incorrect sampling errors (ISE), nor total analytical errors (TAE) crop up in practical operations. There are few systems in which **all** individual fragments are sampled and analysed—but such an SBS system provides another example. One other such system that the author is aware of concerns primary sampling of off-loading streams of industrial fish catches, illustrated in Figure. 4.

Conclusion

This PhD study evaluates the technical and financial characteristics of sensor-based sorting technologies as well as the scenario for its implementation in mining applications. The thesis introduces a technical–economic framework and methodology for project development and evaluation, for implementation, for efficiency testing and optimisation and for future research and development. The Theory of Sampling plays a minor, but far from trivial role in the SBS context.

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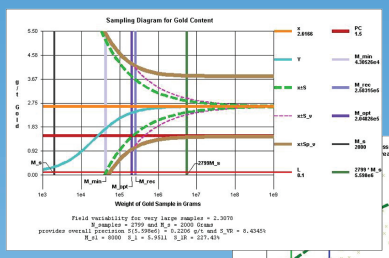

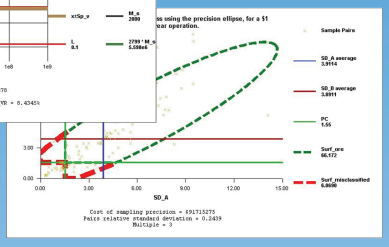

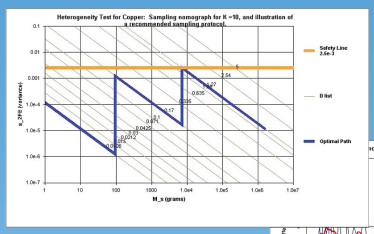

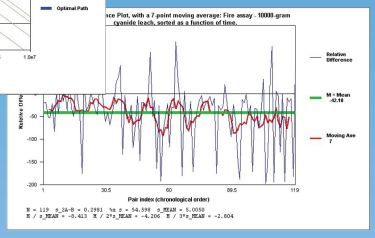

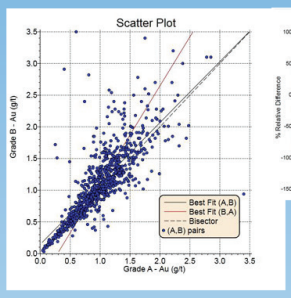

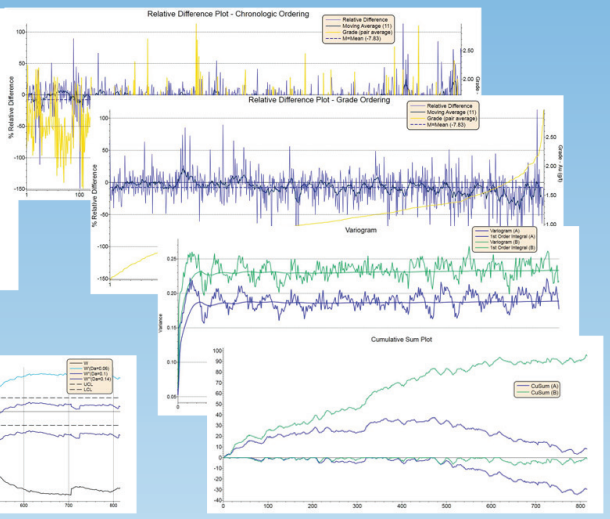

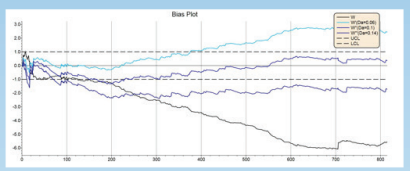

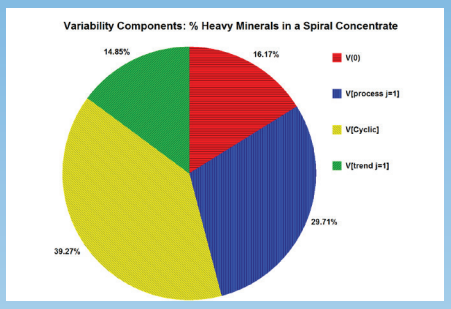

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