



The most common error in applying 'Gy's Formula' in the theory of mineral sampling, and the history of the liberation factor

by D. François-Bongarçon* and P. Gy†

Synopsis

The modern theory of sampling of particulate minerals essentially consists of a recent generalization of the procedures for applying and calibrating the formula usually known as 'Gy's Formula' for sampling variance control, in which the central concept is a parameter called the liberation factor l . A model which can be experimentally adjusted was proposed by one of the authors several years ago, based on geostatistical considerations. This new model, which relates the liberation factor to the sizes of the fragments and mineral grains, solves the usual difficulties faced in the past, and permits predictions that are well verified in practice. Unfortunately, an older, arbitrary and less general formula is still widely used. The vast majority of today's misapplications of Sampling Theory of Particulate Materials can be traced back to the use of this antiquated and generally incorrect model. Following a brief history of the models used for the liberation factor and a description of its main variable, the liberation size, and to illustrate the importance of proper modelling of l , this paper presents demonstrative calculations of the absurdity of the incorrect model using the particular case of gold mineralization as an example, followed by some more positive examples of application.

Introduction

Let us take the example of a gold mine geologist who must decide the sample mass to collect from his primary reverse circulation drilling sample. Knowing that a theory of sampling has been developed and published, he decides to resort to its formula for predicting sampling variances and minimum sampling masses. This formula calls for the calculation of a factor called the 'liberation factor', and some of the most preeminent books on the subject provide rules of thumb and examples for its calculation from the gold liberation size. Since the gold in his case is almost entirely liberated when the ore is pulverized down to a nominal size of 40 microns, and the cuttings have a nominal size of 1.5 cm, the liberation factor l is readily calculated following the published treated example as:

$$l = (0.004 / 1.5)^{0.5} = 0.052$$

This value is then input into the formula, and the sample mass necessary to get a

relative sampling standard deviation (RSD) of 10% is readily calculated. The reader familiar with the formula, or eager to apply formula [1] below, will have no difficulty finding the result: for a 1 ppm Au ore, the minimum sample mass would allegedly be 42 tonnes! Formula [1] would eventually mask the problem and suggest the collection of the entire 200 kg sample interval as primary sample, which is obviously impractical anyway.

At this point, our geologist has three choices:

- ▶ Plan A: Trust his experience, disregard this absurd result, and collect a 40 kg primary sample 'to be on the safe side'.
- ▶ Plan B: Spend days and nights re-doing the calculations, checking and re-checking units and quantities, searching in vain for an elusive mistake in his calculations, until he gives up and applies Plan A.
- ▶ Plan C: Embark on a new phase of research, as one of the authors did, and spend the next five years of his life understanding what is wrong in some modern practical implementations of the otherwise perfectly correct Theory of Sampling, switching to Plan A in case of early discouragement.

In all cases, the switching to Plan A is accompanied with the false and unfortunate but perfectly understandable conclusion that Sampling Theory just does not work. Additionally, the geologist's 40 kg 'safe' sample is insufficient for a 10% standard deviation, and correct calculations show that, at 1 ppm Au, 112 kg would be necessary, although collecting 40 kg would be fine, as the corresponding relative standard deviation

* Agoratek International, Palo Alto, California, USA.
† International Institute of Sampling, Cannes, France.

© The South African Institute of Mining and Metallurgy, 2002. SA ISSN 0038-223X/3.00 + 0.00. Paper received Mar. 2001; revised paper received Aug. 2002.

The most common error in applying 'Gy's formula' of mineral sampling

Nominal Size (cm)	Minimum sample mass for a 10% RSD at 3 ppm Au	
	From Published Example	Correct Implementation
0.635 (1/4")	1.7 t	10 kg
0.168 (10 mesh)	59 kg	1.3 kg
0.0150 (100 mesh)	140 g	37 g

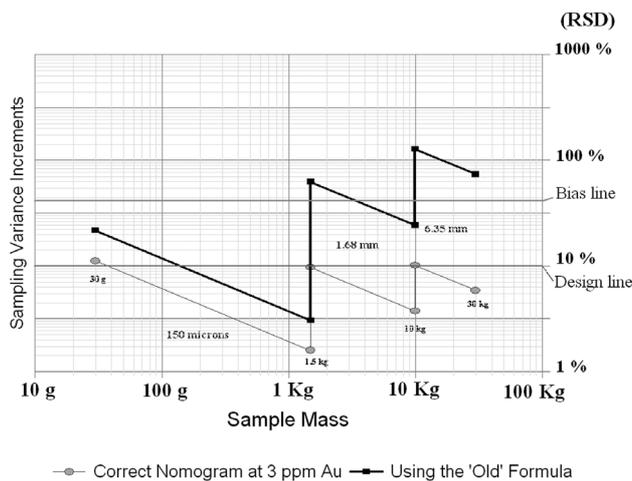


Figure 1—Sampling nomograms

would in reality still be acceptable, at 17%. The Table above compares minimum sample masses at 3 ppm Au for the subsequent stages of comminution in the preparation of that sample, following the published examples and more modern application of the formula:

Assuming a 3-stage sample preparation consisting of a 10 kg split after crushing to 6.35 mm, followed by a 1.5 kg split after crushing down to 1.68 mm, and finally pulverizing to 150 microns before selection of a 30 g fire assay aliquot, Figure 1 shows the sampling nomograms obtained for the correct implementation of the sampling formula, at 3 ppm Au, and for the incorrect one. The classical safety design line (RSD=10%) and the 'bias' line above which sample grade distributions are so skewed that under-reporting of the gold grade becomes a definite risk have also been plotted. As can be seen, incorrect implementation of the formula can lead to disastrous and costly conclusions, such as collecting impractically large sample masses, or instead re-designing the entire laboratory and its equipment.

The theory to the rescue

In response to these difficulties, in the past decade, the numerical part⁽ⁱ⁾ of the Theory of Sampling of Particulate

(i) *The qualitative part, which addresses 'sample correctness' and the problems of sampling biases is even more important: the quantitative aspects are valid only if the sample is correctly taken*

Minerals was the object of new advances (François-Bongarçon, 1991–1998). It is hoped that thanks to these recent advances and corresponding generalizations, the basic theoretical material presented in French engineer Pierre Gy's work (Gy, 1956 to 1998), has been upgraded from its status of a discipline often perceived as mysterious, and little taught or practiced, to that of a better known tool, easier to understand and use than ever before. To this end, the theory is currently being disseminated under this new form through public seminars, organized in mining countries on a regular basis, with the hope that it will soon become part of the regular curriculum in all mining and geology academic programmes.

The unfortunate lack of appreciation for this powerful theory in some corners of the world's mining industry does not stem primarily from its too esoteric presentation in rare textbooks, nor from any kind of weakness of the theory. The theory, while it is often presented in rather cryptic terms to the non-specialist—example of a notable exception is (Gy, 1998)—is demonstrably correct. However, major problems, often reported in its practical applications, especially to low grade minerals (gold, nickel, copper), have hindered its acceptance. These problems, which constitute the actual source of that lack of appreciation, have sometimes been blamed, unjustly, on some 'weakness' of the prescribed formula for calculating the sampling variance, when in fact they come from the arbitrary use of incorrect values for some of its parameters, as was shown in the introduction.

While investigating the sources of the problem, and looking for simpler demonstrations of the formula, one of the authors discovered the exact source of these difficulties (François-Bongarçon, 1991–1998). The formula is commonly expressed as:

$$S_{FSE}^2 = (1/M_S - 1/M_L) f g c l d^3 \quad [1]$$

where S_{FSE}^2 , M_S and M_L are the sampling relative variance, the mass of the sample and the mass of the lot respectively. Constants f and g , usually set to 0.5 and 0.25 respectively, are 'convenience' constants, c is the mineralogical factor, approximately equal to the ratio of the metal density to the dimensionless grade of the lot (in 'per unit'), d is the nominal size of the rock fragments (the mesh size of the screen which rejects five per cent of the material), and ' l ' is the liberation factor (see bibliography for details on these factors).

When $M_S \ll M_L$, formula [1] takes the simplified form:

$$S_{FSE}^2 = f g c l d^3 / M_S \quad [1']$$

Central difficulty: The liberation factor

The liberation factor l is a number between 0 and 1 which varies with the size d of the fragments and also depends on the nominal (or maximum) size of pure metal grains, through the 'liberation size' d_i , and, as it turns out, also depends upon the geostatistical characteristics of the mineralization at microscopic scale (spatial correlations within the fragments). As a result, even for the same metal grain sizes and fragment sizes in two deposits, one would

(ii) *This is often unduly overlooked*

The most common error in applying 'Gy's formula' of mineral sampling

expect different values of the liberation factor if the metals or the mineralogical settings are different. Factor l is a highly variable and sometimes very small quantity: the product cl in formula [1] remains within a limited range of non-extreme values, but the mineralogical factor c can be extremely large for precious metals, being well approximated by the ratio of the density of the mineral of interest to the lot grade in 'per unit', i.e. as a proportion between 0 and 1. For instance in the case of gold, the metal density is 19.3 g/cm^3 , and a grade of 1 ppm is actually 10^{-6} grams per gram, making c equal to $19,300,000 \text{ g/cm}^3$, and l the order of magnitude of its reciprocal (c may seem very large; however, one should realize that, despite its unit, it is not a density, but, in rough terms, the product of a density by a large relative variance). This also means that through factor c , the sampling variance given by formula [1] depends upon the grade of the lot being sampled, and that any use of the formula, or any sampling nomogram derived from it, only makes sense when the grade level at which it is established is duly stated⁽ⁱⁱ⁾. Results derived from formula [1], and the corresponding sampling nomograms are also very sensitive to the variations of factor l .

A brief history of the liberation factor

The 'bulk' of Sampling Theory was developed by Pierre Gy between 1949 and 1951, and by 1953 it became obvious that the liberation factor in his sampling variance formula would be an increasingly delicate issue, even before it was ever applied to precious metals. After it was initially demonstrated its value was a number between 0 and 1, a series of attempts were made, through the years, to estimate/model its value and variations. Lacking the conceptual tools that were developed much later, this was done by means of practical recommendations which tend to appear today as rather arbitrary. The applications made at that time, however, would not (i.e. were not able to) contradict these practices, which included linear variation of l between 0.025 and 0.8 regarded as probable extreme values, and successive tables of recommended values. This was a maturation period of the theory, trying to come to terms with its most difficult problem.

A major breakthrough happened in 1975 when Gy proposed to experimentally model the variations of l as a function of d_l and d , and proposed (as a simple illustrating example) the following equation for the practical calculation of l (Gy, 1982):

$$l = (d_l/d)^{0.5} = \text{SQRT}(d_l/d). \quad [2]$$

The idea—through this 'rough rule of thumb' solely taken as an example—then was to encourage practitioners to develop experiments aimed at studying the patterns of variations of l and customizing them to their particular case. *It never was Gy's intention to give this expression a general meaning.* On the contrary, ever since, Gy repeatedly recommended experimentally estimating the 'heterogeneity invariant' (on which modern experimental calibrations are now based) which includes l as its non-calculable part. Unfortunately, as hinted to in the introduction, certain authors, and many a practitioner, have misinterpreted his recommendations as a license for the generalized use of this model in formula [1], with often catastrophic results, and

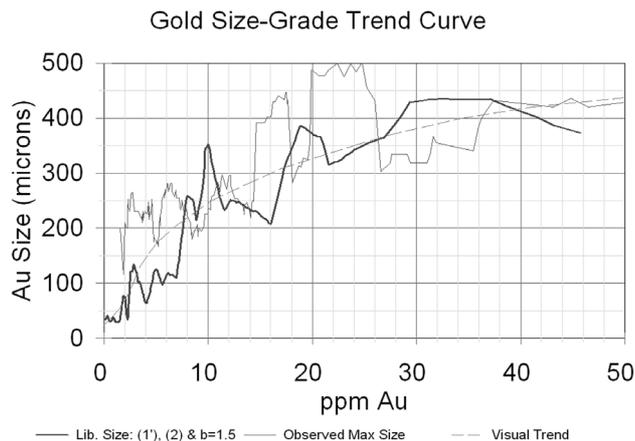


Figure 2—Gold deposit

consequently share their part of responsibility in the unfortunate, progressive abandonment of this useful formula by numerous mining companies and professionals in the precious metals industry.

The liberation size d_l

The concept of liberation size is not trivial, nor is there full agreement on its definition between authors in sampling theory. In our developments, it is the nominal size at which the fragments of the lot must be comminuted so that the mineral grains become fully liberated from their gangue, i.e. each fragment in the lot is either pure mineral or pure gangue. The role of the liberation factor in formula [1] is to express the very different rates of variation of the sampling variance with comminution size above and below liberation size.

Naturally, full liberation is often an ideal concept, and it is useful to substitute it with a practical liberation size, i.e. a nominal size at which most of those fragments which are large enough to bring a non-negligible contribution to the sampling variance have become liberated. Although it does not always perfectly equate to the nominal size of the mineral grains within the rock matrix, this practical liberation size is almost never very far from it, and always of the same order of magnitude. As a result, the liberation is often taken equal to the observed maximum size of the mineral grains, or to their 95% passing size. Figure 2 shows the recent results of a sophisticated experimental application of formulas [1] and [2] above, to establish the relationship between gold grade and gold liberation size from pairs of duplicate assays in the case of a North-American gold deposit. On the Figure, microscopic observations of maximum gold grain sizes at varying grades were also plotted, which show the intimate

(iii) *The liberation size appears in the theory as the ratio of the variances of the individual fragment grades at the fragment nominal size considered, and at liberation size. As a result it makes no sense whatsoever to calculate it from, or equate it to the proportion of liberated mineral grains in the lot at the nominal size under study (i.e. the degree of liberation).*

The most common error in applying ‘Gy’s formula’ of mineral sampling

relationship that exists between the concept of liberation size and the metal grain maximum size.

A new effective model for the liberation factor

Based on these as well as purely geostatistical considerations⁽ⁱⁱⁱ⁾, a fundamental improvement in the form of a simple model, similar to the previous one, but much more adequate, has been proposed by François-Bongarçon for the liberation factor:

$$l = (d_l / d)^b \quad [3]$$

where b is an additional parameter of the model which can be adjusted based on experimental results.

This model [3] has been validated in practice over the past few years with excellent results, including precious metals applications. It has numerous advantages over the model of formula [2].

- ▶ There are good indications of its theoretical validity, including in a particular case of spatial correlations in gold mineralization known as the De Wijsian case, where it can be demonstrated.
- ▶ It makes model [2] appear as a mere particular case (rarely encountered in practice); as a result, model [3] is in no way incompatible with model [2].
- ▶ It can be experimentally adjusted (using methods that are out of the scope of this paper), and therefore allows for full, in-depth customization of formula [1] to the particular deposit or rock type at hand.
- ▶ It resolves the problems of ultra-conservatism often encountered in the classical, albeit usually erroneous application of model [2] in formula [1].
- ▶ It produces sampling nomograms that are realistic and usable.

Additional parameter b , however, triggers more calibration work, more subtle—but strictly necessary—than with simplistic model [2]. Note that this calibration work should never be performed using closely sieved material at small sizes, as is sometimes done, as such a single size fraction is not always representative of the entire crushed material.

In practice, the overall resulting exponent of nominal fragment size d in product $[ld^3]$ in formulas [1] and [1'] is almost never found to exceed the value 2.0 (i.e. a value of b never lower than 1). This had been detected already by empiricists at the turn of the century (Richards, 1908)^(iv), and was pointed out again in a round-table of experts in metrology following Gy's first published work (Experts in Gy, 1956). In the case of gold mineralization, the value of b is almost always experimentally found close to 1.5, resulting in an overall exponent of 1.5 for d also, while the less correct formula [2] would result in an overall exponent of 2.5 (the corresponding experiments are beyond the scope of this

(iv) Although he detected that the overall exponent of d was an important problem, Richards' approach, based on the blind sanction of questionable practices, cannot be considered acceptable from a scientific point of view

paper). In gold, a default value of 1.5 for b is acceptable if only order of magnitude results are sought. In other metals, the value of b is more variable, and/or there have not been enough applications yet to derive reliable trends.

Consequences of an erroneous model for 'l'

Example 1: Calculation of a minimum sample mass, or 'a mine-size sample for you'

In this first example, it is first observed that when using a model such as model [2], all other parameters in formula [1'] can be calculated, and therefore it is possible to solve the formula for the minimum sample mass corresponding to a pre-set sampling variance.

For instance, if we take the case of blast hole sampling in a gold mine, with 2" fragments ($d = 1.27$ cm), a grade of 1 ppm Au ($=10^{-6}$), a density of 19.3 g/cm³ for pure gold, standard values of 0.5 and 0.25 for factors f and g , and a liberation size of 10 microns for gold ($=10^{-3}$ cm, i.e. very fine gold), formula [1'] and model [2] can be combined to derive the sample mass required to achieve a standard deviation of 10 per cent or better (i.e. $S_{FSE}^2 = 0.01$), as follows:

$$\text{With: } S_{FSE}^2 = f g c / d^3 / M_S$$

$$\text{And: } l = (d_l / d)^{0.5}$$

$$\begin{aligned} M_S &= f g c (d_l / d)^{0.5} d^3 / S_{FSE}^2 \\ &= f g c d_l^{0.5} d^{2.5} / S_{FSE}^2 \\ &= 0.5 \times 0.25 \times (19.3 / 10^{-6}) \times \\ &\quad (10^{-3})^{0.5} \times 1.27^{2.5} / 0.01 \\ &= 13.9 \times 10^6 \text{ grams or } 13.9 \text{ tonnes! A totally} \\ &\quad \text{absurd result!} \end{aligned}$$

The gold is very fine, and it is well known, by experience, that samples of a few kilograms to a few tens of kilograms are all it takes to get an acceptable reproducibility. Note that using formula [1] instead of [1'] could have partially masked the high degree of absurdity of the result because it limits, somewhat artificially, the calculated minimum sample mass to no greater than the total mass of the blast hole pile (probably around 400 kg).

Example 2: Calculation of gold liberation size or 'the elusive sub-atomic gold'

In this second example, it is observed that with model [2], it is possible to determine the liberation size d_l in formula [1'], provided the experimental sampling standard deviation has been determined for a given sample mass.

Let us take, for instance the case of a gold ore with an (unknown) liberation size of 15–25 microns (i.e. semi-fine gold). It is well known, by experience, that a blast hole pile with 1 cm fragments of this ore can be sampled with a 10 per cent standard deviation or better, with samples of approximately 15 kg. Under these conditions ($S_{FSE} = 0.10$; $M_S = 15$ kg), we can calculate the liberation size using model [2] as follows:

(v) Although it is still widely (and arbitrarily) used by some professionals and even international standard organizations

The most common error in applying 'Gy's formula' of mineral sampling

$$\text{With: } S_{\text{FSE}}^2 = f g c l d^3 / M_S$$

$$\text{And: } l = (d_l / d)^{0.5}$$

$$l = S_{\text{FSE}}^2 / (f g c d^3 / M_S)$$

$$d_l^{0.5} = S_{\text{FSE}}^2 * d^{0.5} / (f g c d^3 / M_S)$$

$$d_l = [S_{\text{FSE}}^2 * d^{0.5} / (f g c d^3 / M_S)]^2$$

$$= [0.01 \times 10^{0.5} / (0.5 \times 0.25 \times 19\,300\,000 \times 1^3 / 15\,000)]^2$$

$$= 3.9 \times 10^{-9} \text{ cm} = 0.39 \text{ \AA} \text{ngstr\AA} \text{ms!}$$

One would have to (mistakenly) conclude that the gold is indeed very fine, especially since a single atom of gold is estimated to have a diameter of approximately 1.5 \AA ngstr\AA ms.

Conclusions and an example of good application

These results are a demonstration 'ad absurdum' that model [2] is grossly inadequate^(v), and that it is therefore very dangerous to use. As the reader may easily verify, the conditions and premises of these calculations can be changed at will without altering the absurd order of magnitude of the final results, and with the more appropriate default value of 1.5 for *b* in formula [3], these same calculations give a mass of 11 kg and a liberation size of 16 microns respectively, much more in line with the practical experience of centuries of mining gold.

Of interest also is the sampling standard deviation that incorrect formula [2] would attach to these sampling operations when the liberation size is known (10 and 16 microns respectively): 355 per cent for the 11 kg of the first example, and 254 per cent for the 15 kg from the second one. Clearly, when applied to sampling preparation protocols or nomograms, incorrect formula [2] will in many cases ring alarm bells, flash the panic button, and as a likely result, trigger totally unjustified expenses, drastic unwarranted procedural changes, and avoidable equipment purchases.

Conversely, used with a proper model, formula [1] becomes an extremely useful tool. As an example, let us take the case of an ore in which the metal of interest comes from a known sulphide of density of 5 g/cm³ and metal content 25 per cent, which liberates almost entirely at 120 microns. We are asked to decide whether a 100 g split is enough to reasonably sample material crushed to 5 mm when the grade of interest is 0.1% metal. Since we know nothing more, and have no calibration available, we will calculate the sampling variance using equations [1] and [3] assuming the extreme and least favourable value of 1 for *b* in [3]:

$$S_{\text{FSE}}^2 = f g c l d^3 / M_S$$

with: $l = d_l / d$ this becomes:

$$S_{\text{FSE}}^2 = f g c d_l d^2 / M_S$$

as before, $f = 0.5$ and $g = 0.25$. A metal grade of 0.1% corresponds to a mineral grade of 0.4% or 0.004. The variance follows:

$$S_{\text{FSE}}^2 = f g c d_l d^2 / M_S = 0.5 \times 0.25 \times (5/0.004) \times 0.0120 \times 0.5^2 / 100 = (6.85 \%)^2.$$

We have conservatively assumed a value of 1 for *b*. With a higher value, the calculated variance will improve. Since a relative standard deviation of less than 7 percent is within reason, the proposed sampling is perfectly acceptable.

The final word

After these remarks on the quantitative part of Sampling Theory, the authors' main recommendation to the interested practitioners is to perform a full experimental calibration of formula [1] before using it, adopting the model of formula [3] for the liberation factor. A variety of methods have been established to perform such work and are taught in short courses and seminars, described in publications, and available from specialized consultants. In the case of gold, they now include the determination of gold size-grade trend curves.

One should nevertheless be aware that formula [1] quantifies only the most favourable case where not only all biases, but also the effects of any unwanted segregation, have been eliminated or neutralized. Because this is much easier said than done, the 'other part' of Sampling Theory, which is dedicated to *how* samples should be taken, is even more important than what has been exposed in this article. The reader is therefore encouraged to study the entire theory.

Acknowledgements

The authors would like to express their thanks to Dr M. Alfaro, Scott Long, Peter Stoker and to anonymous referees, for their help in making this paper more understandable.

References

- FRANÇOIS-BONGARÇON, D. Geostatistical Determination of Sample Variances in the Sampling of Broken Gold Ores. *CIM Bulletin*. vol. 84, No. 950, 1991. pp. 46-57.
- FRANÇOIS-BONGARÇON, D. The Theory of Sampling of Broken Ores, Revisited: An Effective Geostatistical Approach for the Determination of Sample Variances and Minimum Sample Masses. *Proceedings of The XVth World Mining Congress*. Madrid, 1992-a.
- FRANÇOIS-BONGARÇON, D. Geostatistical Tools for the Determination of Fundamental Sampling Variances and Minimum Sample Masses. *Geostatistics Troia '92*. Kluwer Academic Pub. vol. 2: 1992-b. pp. 989-1000.
- FRANÇOIS-BONGARÇON, D. The Practice of the Sampling Theory of Broken Ores. *CIM Bulletin*. May 1993-a.
- FRANÇOIS-BONGARÇON, D. Comments on F.Pitard's 'Exploration of the Nugget Effect'. *Proceedings of the Forum Geostatistics for the Next Century*. Montreal, June 1993. Kluwer Academic Pub. Dordrecht. The Netherlands. 1993-b.
- FRANÇOIS-BONGARÇON, D. Extensions to the Demonstration of Gy's Formula. *Proceedings of CIM Annual Conference*. Montreal 98. May 1998.
- FRANÇOIS-BONGARÇON, D. Gy's Formula: Conclusion of a New Phase. 1998. ◆

Safe, quick and clean— award winning machine*

A safe, rapid and environmentally friendly method of measuring coal density has won the Australian coal industry's prestigious ACARP research excellence award in coal preparation for 2002.

Developed by the University of Queensland's Julius Kruttschnitt Mineral Research Centre, the UltraSort JK Pycnometer supersedes a laboratory-based heavy liquid technique, and the associated health and chemical disposal risks posed by the old method.

JKMRC researchers Dr Geoff Lyman and Andrew Jonkers won the award for their pycnometer, a technical innovation resulting from the ACARP-funded 'Safe, Rapid Coal Washability Assessment' project.

The JKMRC's innovation was selected from 160 current projects administered by the Australian Coal Association Research Program for the Australian coal industry.

Mr Ross McKinnon, Executive Director of ACARP's management company Australian Coal Research Ltd, pointed out at the ACARP tenth anniversary function in Brisbane recently that a number of the awards for 2002 were given to groups working on the environmental impact of coal mining.

The award to the JKMRC was one such example where the use of organic heavy liquids for float-sink testing had caused increasing concern over potential health hazards.

'A lot of work has been done to find a non-toxic alternative,' Mr McKinnon said. 'The JKMRC has come up with an entirely new approach in which dry density of individual particles is determined by separate mass and volume measurements.'

Geoff Lyman accepted the ACARP award on behalf of the JKMRC and his colleague Andrew Jonkers.

'It's really quite a feather in the JKMRC's cap to be the originators of a project that has led to the successful commercial development of a machine to do this kind of analysis,' Dr Lyman said. 'Gas pycnometers have been around for a long time, but they are slow to use and operate, and there is no way you would consider putting thousands of particles through a conventional laboratory gas pycnometer.'

Dr Lyman explained that the new pycnometer has the capability of analysing 30 particles a minute, equating to the required 3000 particles in 100 minutes to get an accurate measure of the density or washability distribution.

Use of the instrument is at present confined to particles greater than four millimetres.

'It is now possible to put 3000 or so particles into the feed hopper of the machine, choose the density fractions

into which the particles are to be stored, start the machine and come back an hour and a half later and collect the results.'

He said the speed of the new pycnometer is quite remarkable: 'Future models may work even faster'.

During his 28 years as researcher with the coal and minerals processing sector of the mining industry, Dr Lyman realized that one of the major problems in assessing gravity separation processes is an inability to rapidly and safely measure the density distribution of particles.

'For gravity processes, the density is the most important characterization of the mineral to be fed to the separation process,' he said.

'It is on the basis of a coal or mineral particle's density distribution that they are going to be separated, and this particle by particle density information is absolutely invaluable—it's critical to the whole gravity separation process.'

Dr Lyman said that while the pycnometer had been developed to eliminate the use of toxic heavy liquids in the analysis of coal samples, another beneficiary of the technology would be the mineral industry, particularly iron ore and manganese, and anywhere else that gravity processes were used.

'The development of a rapid computerized gas pycnometer for the determination of individual particle densities really marks a genuine breakthrough in laboratory instrumentation and analysis equipment for the mineral industry,' he said.

'Iron ore and non-coal users will now be capable of carrying out very quickly, rapidly and safely densimetric determinations on samples which have never really been possible before.'

Dr Lyman said it was an honour to share in the award: 'It's a great source of satisfaction to have an award from ACARP and the Australian Coal Association which have supported much of our work in the past'.

The pycnometer has subsequently been licensed for manufacture and sale to Sydney-based sorting machine company UltraSort Pty Ltd through the JKMRC's commercial subsidiary JKTech Pty Ltd.

For more information contact: Dr Geoff Lyman by email: g.lyman@mailbox.uq.edu.au ◆

* *Inquiries: David Goeldner, JKMRC Communications Coordinator, Ph + 61 7 3365 5848, email: d.goeldner@mailbox.uq.edu.au*