AN ALL-NATURAL TECHNOLOGY

Paul M. Taylor, Bretby Gammatech, UK, describes two projects employing on-line and portable ash monitoring systems using natural gamma technology.

For the past fifteen years natural gamma has been the unrivalled technology in the UK for the on-line monitoring of the ash content of conveyed coal. This technology has also been researched and used in Australasia for a similar period but it is only in the past couple of years that the UK technology has attracted world attention. This began when Bretby Gammatech, the company formed in 1994 from the privatisation of the British Coal ash monitoring team, made its Natural Gamma Coal Quality Monitor (NGCQM) available to the world market. The company has already installed systems in Hungary, Spain and China.

In response to UK customer demand, the company has recently applied the technology to a portable system for measuring the ash content of coal piles. The first commercial 'ash probe' was commissioned in September 1998, and it has provided the customer with a quick and reliable method of assessing the ash content of coal deliveries. Several ash probes have now been exported to China.

Two monitoring projects are to be examined in this instance, the first a detailed case study showing the long-term performance of an on-line monitor and, more importantly, the benefit the colliery has derived from the good use of the NGCQM data. The second project has employed the use of the ash probe, and the results from an extensive field evaluation are discussed below.

Natural gamma technology

The two instruments rely on the fact that the ash forming shales and mudstones associated with mined coal contain a much higher concentration of naturally occurring radioactive isotopes than the coal itself. The principal contributing isotopes in the ash are potassium^{40} and members of the uranium and thorium radioactive series. The level of gamma radiation emitted from a given weight of mined material increases monotonically with ash content. The relationship at any given site can be determined by laboratory measurement of a suite of samples. Figure 1 provides a graphical representation of the results of such an analysis.

Natural Gamma Coal Quality Monitor (NGCQM)

The NGCQM is a fully on-line instrument providing a continuous measure of the ash content of conveyed coal. Unlike many ash monitors it contains no radioactive sources. The NGCQM calculates the ash content from the simultaneous measurement of the natural gamma radiation emitted by the conveyed material and the weight of that material. The main sensor is mounted under the conveyor in such a manner that it senses the whole load. A large shield (OTBS) containing lead panels is mounted over the conveyor to reduce the effects of normal background radiation. The signals from a small sensor, mounted in the space under the plastic cover on top of the OTBS, are used to compensate the main sensor

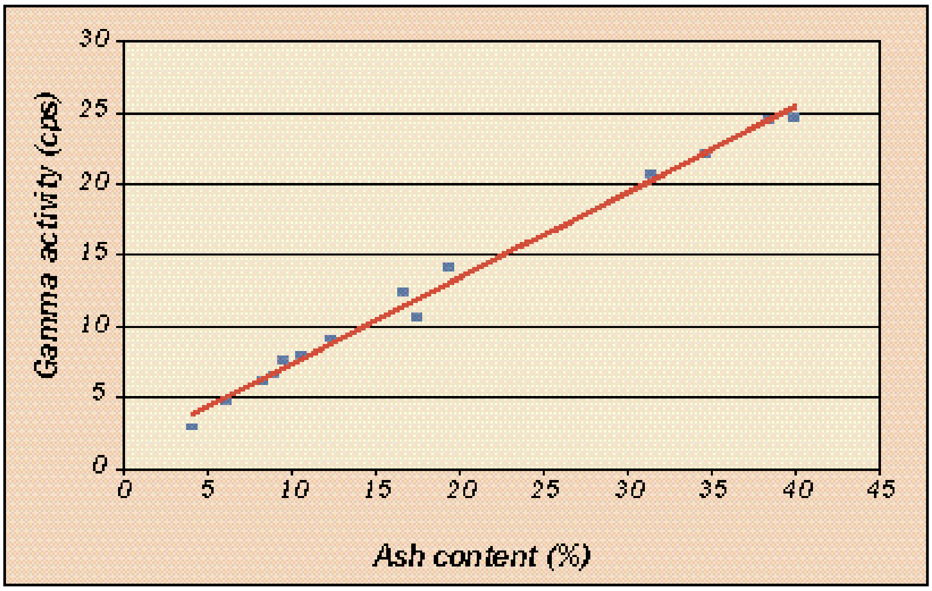

Figure 1. A typical gamma-ash relationship.

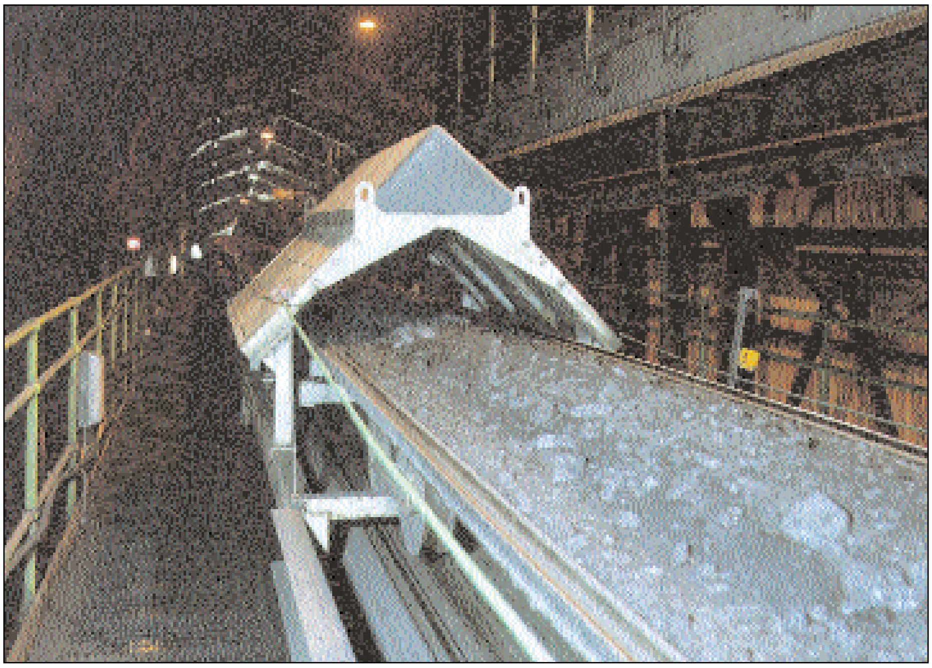

Figure 2. NGCQM installed on a run-of-mine conveyor belt.

Table 1. Monthly comparisons between the NGCQM and two laboratory analyses

Period		NGCQM-Lab 1 (Ash %)			NGCQM-Lab 2 (Ash %)			Lab 1 - Lab 2 (Ash %)		
Start	End	Bias	Sigma	RMS	Bias	Sigma	RMS	Bias	Sigma	RMS
04-Jan	29-Jan	0.24	0.93	0.96	-0.06	0.82	0.82	-0.31	0.53	0.61
29-Jan	27-Feb	0.91	0.75	1.18	0.61	0.76	0.97	-0.26	0.41	0.49
27-Feb	27-Mar	1.20	0.75	1.42	1.10	0.74	1.32	-0.11	0.53	0.54
27-Mar	01-May	0.35	1.00	1.06	0.13	1.14	1.14	-0.32	0.41	0.52
01-May	29-May	0.15	0.79	0.81	0.05	0.74	0.74	-0.11	0.48	0.49
29-May	03-Jul	0.04	0.71	0.71	-0.28	0.68	0.74	-0.32	0.36	0.48
03-Jul	31-Jul	-0.41	0.67	0.78	-0.69	0.63	0.93	-0.28	0.45	0.53

Equation 1. The Grubbs Estimator precision of the NGCQM

$$\{(\text{Variance}_{(\text{NGCQM} - \text{Lab 1})} + \text{Variance}_{(\text{NGCQM - lab 2})} - \text{Variance}_{(\text{Lab 1} - \text{Lab 2})})/2\}^{1/2}$$

Table 2: The monthly dynamic precision of the NGCQM

Period		Precision using Grubbs (ash %)		
Start	End	NGCQM	Lab 1	Lab 2
04-Jan	29-Jan	0.79	0.48	0.21
29-Jan	27-Feb	0.70	0.29	0.30
27-Feb	27-Mar	0.65	0.38	0.37
27-Mar	01-May	1.03	<0.0	0.48
01-May	29-May	0.69	0.39	0.27
29-May	03-Jul	0.65	0.29	0.22
03-Jul	31-Jul	0.56	0.36	0.28

signals from the effects of variations in background radiation. The required tonnage rate and belt speed signals are provided by a standard belt-weigher. Figure 2 shows the NGCQM installed on a run-of-mine conveyor belt and Figure 3 shows a typical screen display.

The NGCQM can be calibrated to span any portion of the range 5-100 per cent ash. The applications for the NGCQM are abundant, ranging from run-of-mine to final product. Several papers outline these in detail[1, 3, 4, 5, 6].

Performance of NGCQM at Gascoigne Wood mine

In September 1998 an NGCQM was installed on one of the parallel conveyor belts transporting power station fuel (PSF) blend to the rapid loading bunker at RJB Mining (UK)'s Gascoigne Wood mine. This NGCQM now acts as a final check on the ash content of trainloads of coal as they are dispatched. The coal is blended using information from a network of six NGCQMs. Two of these monitor the run of mine coming from underground on two large drift conveyors. Their information is used to determine the setting of the screens to route the coal to the appropriate washing facilities. The oversize material is washed by up to eight barrel washers, while the middle size material is washed by a dense medium plant. The undersize material bypasses washing altogether.

NGCQMs mounted on two boom stackers monitor the initially blended material as it is put to stock. Two further NGCQMs, mounted on parallel conveyors, monitor either the freshly blended product as produced on-the-fly or the reclaimed material, as appropriate. The information from these two monitors serves as the method for main blend control to surge bunkers prior to dispatch.

The information from the new installation is used to blend the material from each of the surge bunkers to further homogenise the PSF to the customer's specification. This new installation is the first at Gascoigne Wood to be installed on a final product belt and it is therefore the first that can have direct performance monitoring. The material transported on this belt is sampled by an automated sampling system and two sets of samples are generated. An independent commercial laboratory analyses the first set and the results are used for pricing purposes, while the other set is analysed by the pit laboratory for in-house use.

Bretby Gammatech has monitored the performance of the NGCQM since January 1, 1999. The data for this paper runs to the end of July 1999 – a total of seven months of continuous performance data. During this time there were no recalibrations. The performance monitoring was based upon comparisons of the NGCQM shift ashes with a commercial laboratory (lab 1) determination of one set of sample increments and the pit laboratory (lab 2) determination of the alternate set of sample increments. Over the period of one calendar month this provided between sixty and seventy sets of comparisons. Table 1 shows a summary of the results of three-way comparisons of the monthly data for the seven months. It can be seen that during early February the bias increased from insignificance to just over 1 per cent ash. This increase in bias was due to a slight shift in the background compensation, which was corrected on March 29. Since that date the NGCQM continued to perform with insignificant bias and the RMS error against either laboratory was in the order of 0.8 per cent ash. It can also be seen that there was an average bias of 0.24 per cent ash between the two laboratories.

In addition to the above comparisons, which provide bias and spread information, a detailed analysis was undertaken using the Grubbs Estimator to determine the dynamic precision of the NGCQM[7]. The Grubbs estimator is the recommended technique for the evaluation of the dynamic precision of an on-line analyser in the forthcoming ISO[8].

The precision of each of the two reference laboratories can be determined by suitable substitution in the expression shown in Equation 1. A summary of the precision data is given in Table 2. The results show that the precision of the NGCQM was generally in the order of 0.6-0.7 per cent ash. The only exceptional month was April when the NGCQM precision was 1 per cent ash. This poorer value occurred because of the sudden reduction in bias when the background compensation was updated.

These results are typical for an NGCQM monitoring final product blended power station coal and confirm previously calculated precision levels at a different site[5].

Benefits to Gascoigne Wood

The absolute performance of the monitor is, of course, important, but to the colliery the benefits of using the information to improve the specification of its product is of greater significance. The best way to illustrate the benefit to the colliery is to analyse the Heat Error of its product, both before and after the use of the monitor.

The Heat Error is, in simple terms, the difference between the customer's required specification heat value of the coal and the actual heat value of the supplied coal. Under the terms of most contracts between coal supplier and coal customer there are penalties for supplying high Heat Error fuel. It follows that there is financial incentive to the supplier to keep the Heat Errors low. If it can be demonstrated that the good use of the NGCQM reduces the Heat Errors, then by this criterion alone the purchase of the NGCQM can be justified financially.

Bretby therefore analysed the weekly Heat Errors of the Gascoigne Wood coal delivered by train to a major power utility for a period beginning in January 1998 and ending in July 1999. The NGCQM started to be used at the beginning of October 1998. Figure 4 shows this data as a CUSUM and it can be seen that there was a significant overall improvement in the trend of the mean Heat Error from 414±23kJ/kg to 320±18kJ/kg at the time of the commissioning of the NGCQM. This improvement, while significant, is not as great as has been witnessed in earlier studies[5] but this is likely to be due to the fact that the colliery was already controlling its product reasonably well using its earlier NGCQM installations.

Ash probe

Attention may now be turned to a more recent application of natural gamma technology. In early 1997 two of Bretby's UK customers identified the need for a portable instrument capable of providing a quick measure of the ash content of small piles of coal. After initial investigation such a system was designed, based upon natural gamma. The first production ash probe was manufactured in August 1998 and it has now completed a year of full-time, highly successful operation at a blending plant in South Wales. It is interesting to note that in 1992, Borsaru et al had used natural gamma in a coal face ash analyser[9].

Figure 5 shows the ash probe comprising the probe and display unit. Up to 18 probings per pile can be stored and the average ash content displayed. There is also provision for the recording of up to 18 piles of ash data along with the ability to use up to nine different calibrations. The data can be downloaded to a computer for later analysis. Calibration is straightforward and can be undertaken by the customer using the calibration equipment supplied with the ash probe (Figure 6). Figure 7 shows the ash probe in use.

Performance evaluation

Early in 1999 Celtic Energy, the main coal producer in South Wales, wished to test the ash probe. Its aim was to see if it could be used to measure the ash content of its blended product, known as ESI blend, prior to dispatch from its Park Slip West open cast mine. The ash probe was inserted into several coal piles at the mine and the gamma signals from the probe for each pile were noted. Coal samples were collected using the calibration equipment. These samples were analysed for ash content and the results were obtained early the next day. A calibration was derived and the results are shown in Table 3.

The ash probe was now ready to be assessed seriously. A 30t pile of the ESI blend was spread out on the stockyard and sampled rigorously. A total of 60

Table 3. Results of the first Ash Probe calibration at Park Slip West.

Sample no.	Sample name	Counts (cps)	Analysed ash (%)	Probe ash (%)	Difference ash (%)
1	ESI Blend 1	123.24	15.7	16.8	1.1
2	ESI Blend 2	105.46	13.1	14.6	1.5
3	ESI Blend 3	93.42	14.6	13.0	-1.6
4	Cat 4	153.62	20.1	20.7	0.6
5	Cat 8 A (raw coal)	238.77	30.2	31.5	1.3
6	Cat 8 B (raw coal)	186.36	28.0	24.8	-3.2

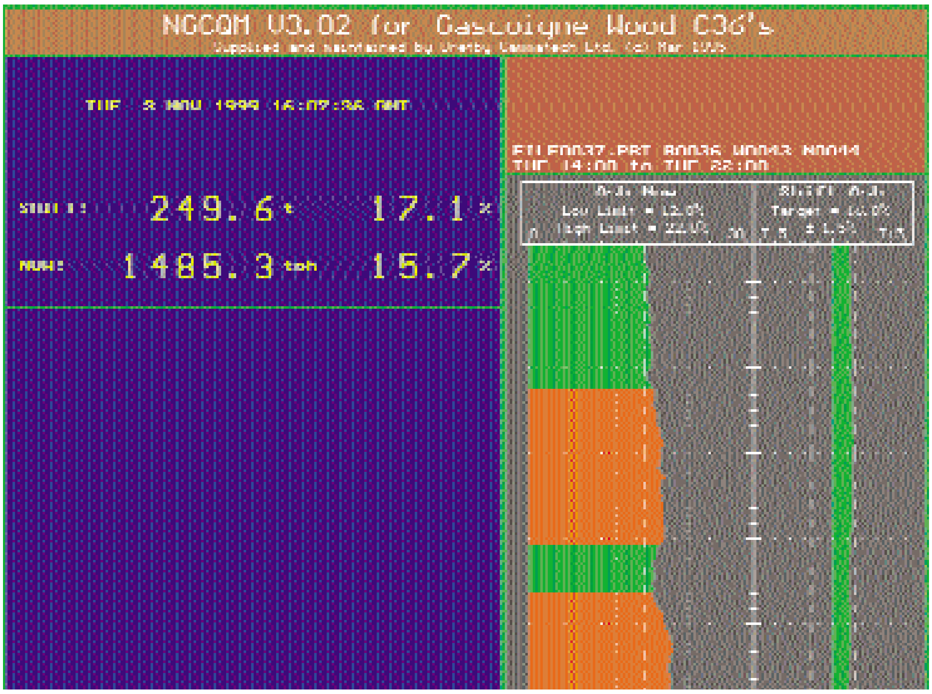

Figure 3. A typical screen display.

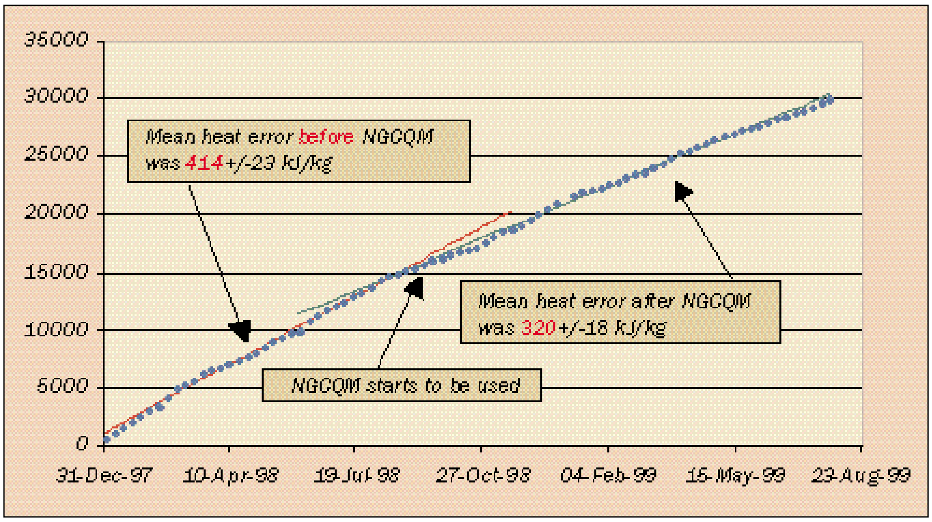

Figure 4. Gascoigne Wood mine: CUSUM of heat errors before and after NGCQM.

increments was taken and the composite sample was suitably prepared for as-received ash analysis. The material was then bulldozed back into a pile again. The Ash Probe was inserted into the pile at eight evenly spaced intervals around the pile and the gamma counts and corresponding ashes were noted for each probing. The individual results are shown in Table 4.

The cumulative average ash shown by the ash probe was 15.2±0.1 per cent, compared with 15.5 per cent ash for the analysis, an error of only 0.3 per cent ash. It can be seen that each individual probing gave very similar results, indicating the homogenous nature of the blended coal. Moreover, the results also show that the calibration was virtually unbiased, indicating that statistical convergence in the calibration had occurred.

Figure 5. The ash probe.

The ash probe was also used to test further piles of Park Slip West material (Table 5). Cal 1 Ash is the same as the Probe Ash in Table 3, whereas Cal 2 Ash is what the ash probe would have read based upon a combined calibration using the data from the two days at Park Slip West.

Sample 2.1 was the pile of ESI blend mentioned above. It can be seen that using a combined calibration derived from the two days' data, the ash probe would have read the ESI Test Pile as 15.7 per cent ash, thus showing a reduction in error from 0.3 per cent to 0.2 per cent ash. Figure 8 shows all the data and the new calibration line (Cal 2).

Benefits of the ash probe

The purchase of any new piece of equipment always has to be justified in financial terms. There are several ways that the Ash Probe can save users money. Some are obvious and easy to quantify in advance, some are obvious but not easy to quantify and others may only appear with experience in using the ash probe. The obvious ones are:

- Savings in the cost of having samples analysed.
- Increased revenue resulting from the more consistent product.
- Increased saleable tonnage. With quicker ash information, suppliers should be able to adjust the ash content of their final product blend to be closer to the maximum allowable under the contract without incurring a reduction in price per tonne.
- If, as a result of the quick ash information, coal suppliers can dispatch their product more quickly, they will avoid it increasing in moisture content during rainy periods when previously it would have been waiting around in the stockyard. This again should reduce penalties and also improve handleability.
- Having ready access to the ash probe will almost certainly mean that users will gain more information on coal ash quality, leading to increased confidence in their operation. Doubt over the ash content of specific material will be removed.
- Coal customers can use the ash probe to check the quality of delivered coal. With the quick results that are possible price reductions can be imposed before accepting the delivery.

These are just some of the benefits that can be and are being derived from using the data from the ash probe.

Conclusions

The seven-month evaluation of the performance of the NGCQM has shown that the monitor can perform without bias and that the RMS error against either laboratory was approximately 0.8 per cent ash. The availability of two reference sets of samples provided the opportunity to undertake a detailed evaluation of the dynamic precision of the NGCQM using the Grubbs estimator as recommended in the forthcoming ISO[7]. The results of this evaluation showed that the NGCQM dynamic precision over many months without recalibration was between 0.6 per cent and 0.7 per cent ash. Even in this example, in which

Table 4. Results of probing the pre-sampled ESI blend pile at Park Slip West

Probe no.	Count-rate (cps)	Count time (sec)	Probe ash (%)	Analysed ash (%)	Difference ash (%)
1	112.35	85	15.44	15.5	-0.06
2	111.93	109	15.38	15.5	-0.12
3	111.02	106	15.27	15.5	-0.23
4	110.12	97	15.15	15.5	-0.35
5	109.66	103	15.10	15.5	-0.40
6	111.6	101	15.34	15.5	-0.16
7	106.91	90	14.75	15.5	-0.75
8	110.45	70	15.20	15.5	-0.30

Table 5. Results of the second ash probe calibration at Park Slip West

Sample no.	Sample name	Counts (cps)	Cal 1 ash (%)	Cal 2 ash (%)	Analysed ash (%)	Cal 1 –analysed ash (%)	Cal 2 – analysed ash (%)
1.1	ESI blend 1	123.24	16.8	17.3	15.7	1.1	1.6
1.2	ESI blend 2	105.46	14.6	15.1	13.1	1.5	2.0
1.3	ESI blend 3	93.42	13.0	13.6	14.6	-1.6	-1.0
1.4	Cat 4	153.62	20.7	21.0	20.1	0.6	0.9
1.5	Cat 8 A	238.77	31.5	31.6	30.2	1.3	1.4
1.6	Cat 8 B	186.36	24.8	25.1	28.0	-3.2	-2.9
2.1	**ESI test**	**110.505**	**15.2**	**15.7**	**15.5**	**-0.3**	**0.2**
2.2	ESI blend 1	108.24	14.9	15.4	15.3	-0.4	0.1
2.3	Current A	70.75	10.2	10.7	11.3	-1.1	-0.6
2.4	Current B	141.65	19.2	19.6	21.3	-2.1	-1.7

the colliery had already been making use of its existing monitors, the information from this latest NGCQM enabled colliery staff to make further significant improvements to an already good average weekly Heat Error. This study has shown that the long-term benefit has been an improvement from 414±23kJ/kg to 320±18kJ/kg in average weekly Heat Error. This represents a very significant financial benefit to the coal producer.

With regard to the new ash probe, details of an on-site calibration have been outlined and the results have been used to provide a rigorous assessment of its ability to accurately determine the ash content of a pile of commercial coal. The results of these field tests have shown that good calibrations can be achieved and under strict conditions the ash content of a coal pile can be tested within a few minutes to an accuracy of better than 0.5 per cent ash.

Feedback from the first ash probe customer has revealed that over the course of one year the instrument has worked reliably and it has not required re-calibration. Accuracy to within 1 per cent ash has invariably been achieved.

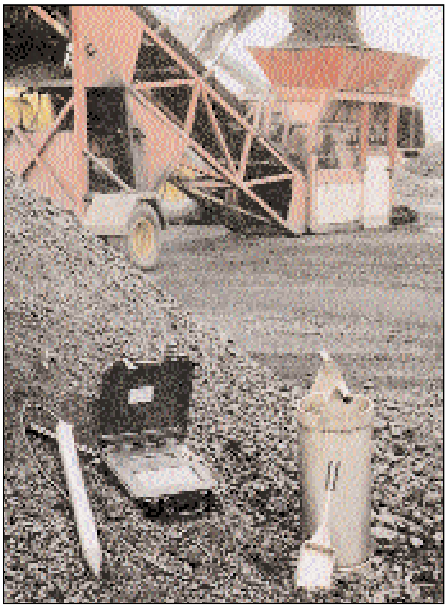

Figure 6. Calibration equipment.

Figure 7. The ash probe in use.

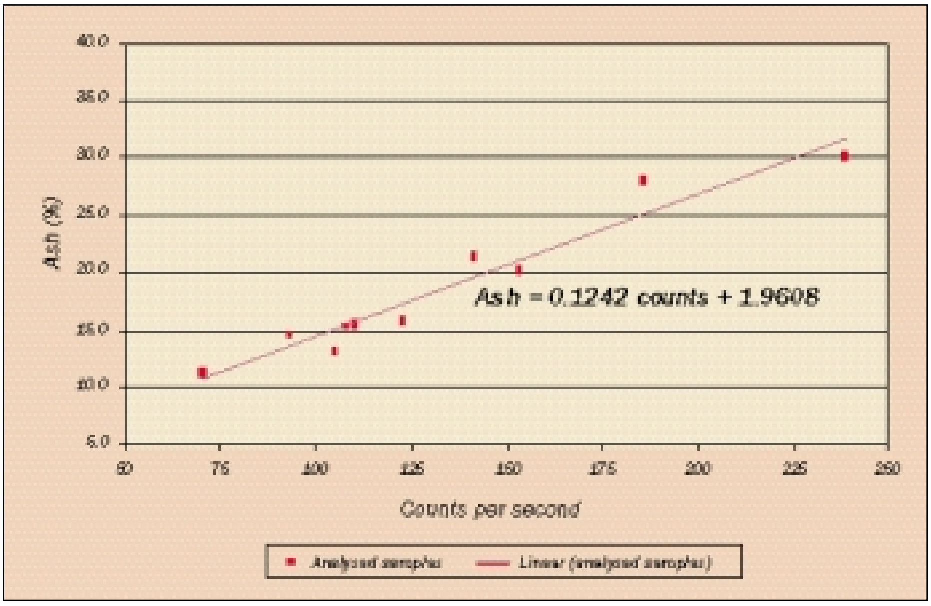

Figure 8. Park slip 2nd calibration.

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