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SRDC final report project BS177S - Proving a natural gamma ray soil monitor in sugar mill application

Olson, BC

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SUMMARY

A commercially available instrument for measurement of soil in cane supplied to mills has been successfully commissioned at Tully Sugar Limited and is being used for cane payment and by mill personnel as an alarm for high soil levels in the cane supply.

A method of measurement of soil in coal based on the gamma radiation emitted by the soil has been developed by CSIRO, Minerals Division. An extension of this was to investigate whether the same technique could be used to measure soil in sugarcane consignments. As the initial experiments at the mill operated by Tully Sugar Limited indicated that this might be possible, an experimental gamma radiation detector system was installed in 1993 at Tully Mill; data collected and soil prediction equations developed through the years 1993 to 1996. Based on the prediction results obtained from the CSIRO unit, a commercial instrument, a CANESCAN 1500, was purchased and installed for the 1997 crushing season. This was supplied by Scantech Limited, formerly known as MCI Limited.

The installation arrangement of the CANESCAN differed from the CSIRO instrument with respect to both the orientation of the detector relative to the belt conveyor carrying the cane and to the shielding for background radiation attenuation. Although the size of the detector (scintillation tube) was identical to that used in the CSIRO model, these differences dictated that new calibration equation(s) be developed. Prior to 1997 the soil predictions using the CSIRO instrument had been used in the cane payment system.

Consequently, there was a need to quickly develop new equations. In 1996 it was reasoned that, because the biomass (cane) contains the gamma emitting isotope potassium 40, the relative contribution of the biomass would increase as the soil content decreased. This, therefore, should result in a change in the relationship between the measured counts per second of gamma radiation and the soil content of the cane supply. This approach led to the following ash prediction method. A preliminary ash estimation equation was applied. Depending on the result of this estimate other equations were used to obtain a final value. These equations were used throughout 1997 and 1998.

A performance objective was set based on the prediction experience prior to 1997. This was that 95 percent of predictions should have errors not greater than ± one percent ash, equivalent to a standard error of prediction of 0.5 percent ash. This was not met in 1997 and 1998 with only 88.1 percent of the data falling within these limits. As for the CSIRO instrument data, there was a trend to overestimate at low ash values and underestimate at high ash. Within this trend there were some extreme errors at both high and low ash levels.

The initial, incorrect assumptions made in the development of this prediction method were that the counts per second of gamma radiation would increase in a linear manner with both percent ash and the radioactivity per kg (specific activity) of the soil. Analysis of data and modelling of the effect of the gamma radiation of the biomass as a function of both percent ash and specific activity has been useful in the explanation of the errors obtained in 1997 and 1998. This analysis has shown that the major influence
has been the contribution of the potassium 40 isotope in the biomass. Although no quantitative measure of the effect of extraneous matter, or leaf content has been obtained, it is apparent that it is a significant factor. Statistical, but not experimental evidence, strongly suggests that the biomass contains isotopes that contribute radiation in the thorium channel and that this is influenced by the percentage of leaf material in the cane supply. Statistical analysis also suggests that dry, dusty, harvesting conditions can result in a high specific activity clay film on the surface of the cane and leaves. This causes overestimation of the ash content.

This analysis explained why an equation using only the counts per second measured and the specific activity of the soil were inadequate in prediction for many cane samples.

Equations were developed for use in 1999 by dividing the data into ranges of specific activity of soil and a subset that could be clearly identified as having high ash. For the first six weeks an improvement in performance relative to the two previous years was obtained. After omitting two of 136 trials because of identifiable problems with the data, 92.6 percent were within ± one percent ash. The percentage of high ash samples is greater than in the data set used for development of the prediction equations. This would be expected to reduce the accuracy of the estimates.

Sufficient understanding of the system has been obtained to establish causes of error for particular samples. Therefore, further improvements are possible with the addition of new data for regression development.
1.0 BACKGROUND

Soil in sugarcane supplied to mills is a major industry concern, causing wear on milling trains and in boilers, increased difficulty in clarification and additional costs and sugar losses in handling mud solids. Sugar quality is also at risk. Visual assessment of soil in cane has been used but this method is inaccurate.

Development of a method for measuring soil in cane based on the natural gamma radiation from soil commenced at Tully Mill in 1992 in conjunction with BSES and CSIRO (Minerals Division). A prototype instrument was obtained from CSIRO for the work. Success with this experimental monitor up to and including 1996 resulted in support from SRDC to purchase and evaluate a commercial instrument from Mineral Control Instrumentation Ltd (now Scantech Ltd). A CANESCAN 1500, based on a model successfully applied to the coal industry, was installed at Tully Mill for the beginning of the 1997 season. The new instrument was required to provide improved reliability and availability of technical backup compared with the experimental monitor. It also provided greater precision for counts per second (cps) data, enabling the use of separate values for each of the potassium (K), uranium (U) and thorium (Th) channels in addition to total cps in prediction equations.

Although the work with the CSIRO instrument showed that soil in cane could be measured, several phenomena needed to be resolved. It had been observed that soil predictions tended to be overestimated during dry weather periods and to be underestimated in wet weather. A distinctive diurnal cycle had been observed for the predicted soil in cane. Also, large peaks in gamma radiation occurred prior to the arrival of a storm.

2.0 PROJECT OBJECTIVES

- To develop the method of analysis for soil in cane by use of its natural gamma ray emission.
- To lease and install a CANESCAN 1500 natural gamma ash monitor on the cane elevator at Tully Mill.
- To prepare a calibration equation linking counts per second received by the CANESCAN detector and soil in cane and in so doing research the relationships between soil characteristics, cane and the environment that affect the calibration. Assess the importance of ash content of clean cane in interpretation of counts per second results.
- Determine the effect of inherent specific activity of the soil and understand and correct for any variations that can result in large errors, such as the presence of non gamma-ray emitting substances.
- Evaluate the effect of wet weather/dry weather interference in the calibration.
- Resolve the reason for the adverse effect of storm events and gamma storms on the accuracy of the measurement. Ascertain the benefit of a separate background counter.
- Determine the influence of time of day, time of year and temperature effects on the results obtained and correct for these in the calibration or by alternate means.
Identify the most appropriate positioning of the sensor and the relative contribution of accurate tonnage per hour devices such as belt weighers and simple cane height measurement to the final calibration accuracy.

Evaluate the reliability of the instrument in the environment of a sugar mill.

Identify the relationship between other extraneous matter and measured soil content of the cane.

2.1 Alteration to project objectives

Tully Sugar has negotiated with SRDC that the CANESCAN unit be purchased by Tully Sugar in lieu of the lease agreement originally approved. There will be no change to the funding provided as a result of this.

The CANESCAN 1500 was installed and successfully commissioned. The effects noted in the objectives have been investigated and methods to either compensate for or otherwise handle these have been developed and incorporated within prediction equations.

3.0 METHODOLOGY

3.1 Basic concept

Geological materials such as soil contain traces of naturally occurring radioactive elements including potassium, uranium and thorium. Potassium and daughter products of uranium and thorium produce penetrating gamma rays that can be measured with the aid of an efficient gamma ray detector. For a mixture of cane and soil the amount of radiation is dependent on the amount of soil, the degree of radioactivity (specific activity) of the soil, the quantity of the cane/soil mixture and the geometry of the detector and cane supply. Therefore, for a given detector and installation arrangement, the amount of soil should be able to be computed from the gamma ray count, the specific activity of the soil and the amount of cane being monitored.

3.2 Specific activity measurement

Specific activity for each block was determined using a portable Eberline SPA-3 gamma measuring instrument. This was mounted below the front of a vehicle. Gamma radiation from the soil was measured over 10-second intervals while the vehicle was stationary and the driver was in the cab. The values of cps of gamma activity emitted by the soil at the corners and along the sides of each block were averaged and then converted to specific activity using a table. The relationship between cps and specific activity is linear.

3.3 Installation

An efficient NaI (Tl) gamma-ray detector is used in the soil monitor for the detection of gamma radiation from sugarcane billets on the conveyor belt between the tippler and the shredder. It is arranged lengthwise underneath the belt and a combination of lead and steel shielding over the top and sides is used to reduce background cosmic and terrestrial radiation in order to increase the signal to noise ratio. The CANESCAN 1500 installation arrangement is different from that used for the CSIRO detector in that the detector housing was aligned along the belt rather than across it and the shielding was
consequently longer. This was necessary because of the differences in shielding arrangement within the detector boxes.

The signals are fed into a preamplifier and a multi-channel analyser. The output is integrated in selected energy regions providing the total cps and values for the potassium, uranium and thorium ranges. The CANESCAN 1500 provides two RS422 ports: one for communication with a host computer system and the other for remote management of the device.

In analysis mode the soil monitor sends regular messages to the host computer while the conveyor belt is running. The frequency of these messages can be adjusted as required. The scan cycle was set to 30 seconds.

A belt weigher is installed just before the gamma detector to feed belt motion and tonnage data to the soil monitor. From this, belt speed, load factor, and tonnes per hour (tph) are calculated for each sample. The load factor (or load) is defined as the tonnes per unit length of belt. The tonnes of cane measured by the belt weigher were regularly compared with the tonnes of cane measured at the weighbridge as a check on accuracy.

Cane is tracked through the soil monitor using the same tracking technique as used for juice sample collection. To establish the correct timing, the number of tracking pulses from when the cane is tipped to when it reaches the monitor was determined by visual observation. This was done several times. A 30-second wash period was allowed at the beginning and end of each rake. As signals from the monitor were obtained every 30 seconds, it was possible to check the timing regularly on the basis that a change in sample normally results in a change in counts per second.

When the first bin of a sample reaches the detector, a reset signal is sent to the monitor by the host computer to clear the tonnes accumulator. The average specific activity for the block from which the cane was harvested is then retrieved from the farm database.

The first data message received after the reset signal is discarded to prevent contamination from the previous sample. Subsequent data messages are decoded to acquire machine status, the total cps, the counts for the K, U and Th channels and tonnes scanned in the current scan cycle. The counts are then tonnage-weighted to eliminate empty belt scans. For a soil determination to be valid, at least two minutes of scan time and twenty tonnes of cane must be processed. When sufficient data has been collected, the percent soil is calculated from the accumulated data. This interim calculation is used to trigger alarms for the Chief Cane Inspector and Shift Chemist if the soil prediction exceeds preset thresholds. After the last bin of a sample has reached the detector, results are tallied and, if valid, are written to file.
3.4 Calibration

Although the type and size of the gamma radiation detector was the same for the CSIRO and CANESCAN instruments, a new calibration equation had to be developed in 1997. This was due to the changes in the installation arrangement of the detector (along the belt cf across it) and the consequent changes in the geometry of the shielding. It had been hoped that the two instruments could be run in series initially, permitting a comparison of results. Space restraints under the belt prevented this.

3.4.1 Sampling

Trial runs were carried out to calibrate and evaluate the performance of the monitor. Prepared cane for a rake was sampled at the fibre door. The timing of this was coordinated with the collection of cps data through the cane tracking system. Sampling was carried out over the whole rake, with as many small samples as possible being taken, this being limited by the time necessary to return the excess fibre to the chute. The small samples were combined, the total sample ranging from 10 to 20 kg. The fibre was mixed and two 200g sub-samples taken for ash determination by ignition at 600°C. The two ash results were averaged to give a percent ash for each rake. This value was taken to be the measure of soil in the cane supply and was used as the independent variable in development of calibration equations. It should be noted that this ash value contains a component from the biomass itself.

3.4.2 Measurement of cane properties

At the end of 1996 it was acknowledged that the potassium content of the biomass would probably be a significant source of gamma radiation, particularly at low ash levels and that parameters describing this potassium contribution might be necessary in any prediction equations. These measurements had to be readily available or easy to obtain with robust technology. Throughout 1997 and 1998 conductivity, brix, and percent impurities of juice were recorded. The conductivity of routine cane payment juice was used in the data analysis. This was determined using a laboratory Yokogawa Model SC82 meter. The readings were corrected to a constant 25°C. Spindle brix and pol for routine samples were retrieved from the cane payment computer system.

A system for on-line conductivity using an inductive method was installed for the 1998 season but was not fully commissioned.

3.4.3 Background monitor

To study the variations in, and the effects of background radiation, a separate detector with only a total cps output was installed after the start of the 1998 season. This unit was designed and built by CSIRO. During periods of mill downtime the radiation measured by the CANESCAN with an empty belt was compared with that measured by the background detector. This comparison is the basis of development of prediction adjustment methods.

3.4.4 Equation development

Multiple linear regression techniques using Statistix© software was applied to obtain calibration equations.
In 1993, a calibration equation, based on the type used in the coal industry, was developed using the total counts per second, specific activity and log TPH. At the end of 1996, it was recognised that this equation might not adequately describe the system in two aspects. The first is that it ignored the biomass contribution. Also, TPH is intended to be a measure of the amount (depth) of cane that the monitor scans. As belt speed is variable, it was expected that a better parameter might be the weight of cane per unit length (ie load).

Throughout the duration of this project additional variables and more complex equations have been explored. These included the properties of first expressed juice, load, the four cps values, ratios between these four values and ratios of the cps values to the specific activity.

Regression analysis was also carried out on data subsets selected on the basis of ranges of variables such as specific activity.

4.0 RESULTS

4.1 Performance objectives

Based on the very early trials in 1993, it was concluded that a realistic objective for the method was that 95 percent of results should be within ± one percent ash, ie equivalent to a standard error of prediction of 0.5 percent. It is recognised that the relative error (error/measured ash) is also a relevant measure of performance. That is, an error of one percent at a low level of ash level is more significant than the same error at a much higher ash content.

4.2 Regression analysis

From 1993 to 1996 the simple three term equation provided consistent accuracy with just fewer than 90 percent of errors being within ± one percent ash. A tendency to overestimate at low ash and underestimate at high ash was observed.

In 1997, prior to sufficient belt loading and conductivity data being available, a regression equation was required for the CANESCAN instrument so that soil levels could continue to be used for cane payment purposes. Using a calibration data set of 261 trials, the following prediction equation was developed:

\[
\text{% Soil} = -0.738 + 0.132 \times \text{cps} -0.033 \times \text{Specific Activity} -2.065 \times \log (\text{tph}) \quad \text{(1)}
\]

On the basis that the radioactivity of cane ash would become more significant as the total ash became less, and that the relationship between percent ash and cps would vary with percent ash, the use of specific equations applied to various ranges of total ash was explored. It was found that a better standard error for the same calibration data set resulted from using the four cps values provided by the instrument and their ratios relative to specific activity and between each other. This approach led to development of a preliminary prediction that was divided into three ranges. Other regressions were then applied to each of these ranges. The equations obtained and used for prediction in 1997 and 1998 are:
\[
\% \text{Soil} = 1.366 + 3.227 \times \text{Fn1} + 0.0174 \times \text{Fn4} - 365.1 \times \text{Fn6} - 0.0052 \times \text{TPH} + 0.0120 \times \text{S} \quad \text{.............. (2)}
\]

\[
\% \text{Soil} = 1.49347 + 9.001 \times \text{Fn1} + 0.0118 \times \text{Fn4} - 0.02245 \times \text{Fn9} - 0.0031 \times \text{(tph)} \quad \text{........................ (3)}
\]

\[
\% \text{Soil} = -0.1514 + 5.268 \times \text{Fn1} + 0.0662 \times \text{Fn3} - 151.85 \times \text{Fn6} + 0.0011 \times \text{Fn7} + 0.1016 \times \text{Fn9} \quad \text{.............................................. (4)}
\]

Where:

\[
\text{Fn1} = \frac{\text{(Total cps)}}{\text{Specific activity of soil}}
\]

\[
\text{Fn3} = \frac{\text{(Total cps)}}{\text{(cps for K channel)}}
\]

\[
\text{Fn4} = \frac{\text{(cps for K channel)}}{\text{(cps for U channel + cps for Th channel)}}
\]

\[
\text{Fn6} = \frac{\text{(cps for U channel)}}{\text{Specific Activity of soil}}
\]

\[
\text{Fn7} = \frac{\text{(cps for K channel)}}{\text{(cps for Th channel)}}
\]

\[
\text{Fn9} = \frac{\text{(cps for U channel)}}{\text{(cps for Th channel)}}
\]

\[
\text{S} = \text{Specific activity of soil}
\]

Note: The symbol \( \Delta \) indicates that average background radiation is subtracted.

Several measurements were made during down-time when the belt was empty. These were used to determine the cps of background radiation. The values obtained and used in the prediction equations are:

- Total cps .............................................. 64.13
- Potassium channel .............................. 1.136
- Uranium channel ................................. 0.470
- Thorium channel ................................. 0.517

Equation (2) is used as a preliminary estimate. When the predicted soil using equation (2) is greater than two but less than three percent, equation (3) is applied to obtain the final prediction. Similarly, when equation (2) produces a result that is less than or equal to two percent, equation (4) is applied. For values greater than three percent, the preliminary estimate (equation 2) is accepted.

Over the development phase, a continuous audit has been maintained. A total of 1,041 audits over two years have enabled a comprehensive statistical analysis of the performance of the CANESCAN monitor. Selection of consignments to audit was essentially random with little emphasis on particular areas or farms.

Constant liaison was maintained with growers and harvester operators through the cane inspectors. If concerns were expressed about unexpectedly high predictions and other evidence suggested a problem, targeted audits were undertaken. In review of the two years' sampling using the Assignment GIS, it was established that all areas were reasonably represented.

### 4.3 Ranges for primary variables for 1997 and 1998 samples

Table 1 shows the ranges and average values for the primary variables in the trials carried out in 1997 and 1998.
Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent ash</td>
<td>0.5</td>
<td>11.3</td>
<td>2.08</td>
<td>1.28</td>
</tr>
<tr>
<td>Specific activity</td>
<td>14</td>
<td>108</td>
<td>63.4</td>
<td>16.8</td>
</tr>
<tr>
<td>Total cps</td>
<td>64.83</td>
<td>129.73</td>
<td>81.39</td>
<td>9.46</td>
</tr>
<tr>
<td>Potassium channel cps</td>
<td>1.54</td>
<td>5.43</td>
<td>2.64</td>
<td>0.49</td>
</tr>
<tr>
<td>Uranium channel cps</td>
<td>0.36</td>
<td>1.14</td>
<td>0.56</td>
<td>0.10</td>
</tr>
<tr>
<td>Thorium channel cps</td>
<td>0.41</td>
<td>1.71</td>
<td>0.75</td>
<td>0.18</td>
</tr>
</tbody>
</table>

4.4 Predictions and errors for 1997 and 1998

Figure 1 is a time series chart of prediction errors for 1997 and 1998 audit samples. The errors for both audit samples and samples to follow up suspected problem results are plotted as a function of percent ash and specific activity in Figures 2 and 3 respectively. This data is also summarised in the following table. Error is calculated as predicted ash minus measured ash.

Table 2 Summary of prediction errors

<table>
<thead>
<tr>
<th>Variable Range</th>
<th>Samples</th>
<th>Using equations 2, 3 and 4</th>
<th></th>
<th>Using equation 1</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Error range</td>
<td>% to ± 1</td>
<td>Mean</td>
</tr>
<tr>
<td>All</td>
<td>1041</td>
<td>0.03</td>
<td>-6.06 to 3.96</td>
<td>88.1</td>
<td>0.08</td>
</tr>
</tbody>
</table>

DATA BASED ON PERCENT ASH RANGES

<table>
<thead>
<tr>
<th>Variable Range</th>
<th>Samples</th>
<th>Using equations 2, 3 and 4</th>
<th></th>
<th>Using equation 1</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Error range</td>
<td>% to ± 1</td>
<td>Mean</td>
</tr>
<tr>
<td>&lt;1</td>
<td>142</td>
<td>0.53</td>
<td>-0.53 to 3.96</td>
<td>83.1</td>
<td>0.48</td>
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<tr>
<td>1.0 – 1.499</td>
<td>307</td>
<td>0.29</td>
<td>-0.50 to 3.20</td>
<td>93.5</td>
<td>0.25</td>
</tr>
<tr>
<td>1.5 – 1.999</td>
<td>220</td>
<td>0.09</td>
<td>-0.92 to 2.49</td>
<td>95.5</td>
<td>0.11</td>
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<tr>
<td>2.0 – 2.499</td>
<td>135</td>
<td>-0.16</td>
<td>-1.14 to 1.67</td>
<td>93.3</td>
<td>-0.01</td>
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<tr>
<td>2.5 – 2.999</td>
<td>94</td>
<td>-0.39</td>
<td>-2.17 to 2.28</td>
<td>83.0</td>
<td>-0.21</td>
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<td>3.0 – 4.0</td>
<td>77</td>
<td>-0.44</td>
<td>-1.84 to 1.56</td>
<td>79.3</td>
<td>-0.27</td>
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<td>&gt;4</td>
<td>66</td>
<td>-0.91</td>
<td>-6.06 to 2.53</td>
<td>56.1</td>
<td>-0.64</td>
</tr>
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DATA BASED ON SPECIFIC ACTIVITY RANGES

<table>
<thead>
<tr>
<th>Variable Range</th>
<th>Samples</th>
<th>Using equations 2, 3 and 4</th>
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<td></td>
<td></td>
<td>Mean</td>
<td>Error range</td>
<td>% to ± 1</td>
<td>Mean</td>
</tr>
<tr>
<td>14 – 40</td>
<td>105</td>
<td>0.47</td>
<td>-2.81 to 3.96</td>
<td>65.7</td>
<td>0.35</td>
</tr>
<tr>
<td>40 – 49</td>
<td>101</td>
<td>0.13</td>
<td>-6.06 to 2.34</td>
<td>78.2</td>
<td>0.17</td>
</tr>
<tr>
<td>50 – 59</td>
<td>204</td>
<td>0.05</td>
<td>-2.67 to 2.16</td>
<td>87.7</td>
<td>0.16</td>
</tr>
<tr>
<td>60 – 69</td>
<td>287</td>
<td>-0.03</td>
<td>-2.17 to 2.49</td>
<td>94.4</td>
<td>0.06</td>
</tr>
<tr>
<td>70 – 79</td>
<td>172</td>
<td>-0.08</td>
<td>-3.04 to 2.53</td>
<td>92.4</td>
<td>-0.04</td>
</tr>
<tr>
<td>&gt;80 – 108</td>
<td>172</td>
<td>-0.11</td>
<td>-1.99 to 1.34</td>
<td>93.0</td>
<td>-0.06</td>
</tr>
</tbody>
</table>

Both prediction models over-estimate at low ash levels and low specific activities and under-estimate at high values of these. The means of ash and specific activity for this data set are 1.96 and 62.5 respectively. Note that the best results with respect to mean error
and predictions within ± one percent are in ranges around these values. The overall results from the two prediction methods are similar. For low ash values Equations 2, 3, and 4 perform better than Equation 1 on an average but can result in more severe over-estimation. Samples with high soil levels or low specific activities are not predicted particularly well.

In the ongoing review of predictions, it has been established that one location known as Caravan Hill and a farm in the Lower Tully area are consistently over-estimated. Soil samples were collected and their gamma emissions obtained to determine if and how these differ from other soils.

Regression analysis has shown that the juice properties are statistically significant in the relationship between ash and the monitor readings. A single equation that included the juice properties, conductivity, brix and percent impurities was developed on 1997 data. The performance of this equation was tracked in 1998 with the hope that it would reduce the errors. However, despite regression analysis showing that these properties are significant, no overall improvement resulted except at low specific activities.

### 4.5 Results from regressions developed for use in 1999

Because of the deficiencies in the equations used in 1997 and 1998 and as a result of additional analysis of the data, new equations have been developed for use in 1999. For the regression data set, 97 percent of the results were within ± one percent ash. Errors for these new equations are plotted as a function of percent ash in Figure 4. It should be noted that this is a smaller data set than that used in Figures 2 and 3 (764 trials versus 1041). The reason for this is that conductivity and load, parameters that are used in the new equations, are not available for all trials. For these 764 trials only 87 percent of the errors determined using equations 2, 3 and 4 were within ± one percent. The development method for these new equations is provided in the discussion.

Time series plots of absolute and relative errors for the first six weeks of the 1999 season are shown in Figures 5 and 6 respectively.

In Figure 5 it can be seen that the ‘error’ for trials 112 and 132 are very high. By analysis of the raw data for trial 132; comparison with a trial from the same block in 1998 and comparison with other trials having similar specific activity and measured ash content, it has been concluded that a significant sampling error occurred. The predicted ash was very close to the actual ash.

The cane supply from trial 112 is abnormal. The crop was planted in 1998 after the field had been used for banana growing. Because of the high fertiliser application for the bananas the cane exhibited extremely high potassium content for the level of ash measured. The data indicates that the sample had a very low extraneous matter content and extremely low soil content. This combination usually results in an ash well below one percent. The measured ash was 1.54 percent indicating a very high soluble ash content in the cane.

After omitting these two samples from the data set the 1999 results are compared with the 1997/98 results in Table 3.
Table 3  
Comparison of 1999 results with 1997/98 results

<table>
<thead>
<tr>
<th></th>
<th>1997-98</th>
<th>1999</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of samples</td>
<td>1041</td>
<td>134</td>
</tr>
</tbody>
</table>

**Absolute error**

<table>
<thead>
<tr>
<th></th>
<th>1997-98</th>
<th>1999</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>Standard error of prediction</td>
<td>0.72</td>
<td>0.53</td>
</tr>
<tr>
<td>Percent within +- one percent</td>
<td>88.1</td>
<td>92.6</td>
</tr>
</tbody>
</table>

**Relative error**

<table>
<thead>
<tr>
<th></th>
<th>1997-98</th>
<th>1999</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average relative error</td>
<td>0.13</td>
<td>0.06</td>
</tr>
<tr>
<td>Standard error of prediction</td>
<td>0.52</td>
<td>0.27</td>
</tr>
<tr>
<td>Percent within 0.5 percent</td>
<td>85.7</td>
<td>94.8</td>
</tr>
</tbody>
</table>

It can be seen that the new prediction method has resulted in significant improvements. The objective of 95 percent of errors within ± one percent has not been achieved. One reason for this is that there is a higher proportion of high ash samples in the 1999 data set.

Overestimation of the Caravan Hill farms has been significantly reduced with the new equations but still occurs. Additional adjustment methods were developed for these farms. Samples from these farms have been intentionally targeted in 1999. The results from 1997/98 and 1999 are compared in Table 4. With the exception of one sample for Farm ‘A’, all results for 1999 have been within one percent of the measured ash.

Table 4

<table>
<thead>
<tr>
<th>Farm ‘A’</th>
<th>1997/98</th>
<th>1999</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samples</td>
<td>15.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Average error</td>
<td>1.38</td>
<td>-0.19</td>
</tr>
<tr>
<td>Maximum error</td>
<td>3.96</td>
<td>0.52</td>
</tr>
<tr>
<td>Minimum error</td>
<td>0.05</td>
<td>-1.25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Farm ‘B’</th>
<th>1997/98</th>
<th>1999</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samples</td>
<td>14.00</td>
<td>5.00</td>
</tr>
<tr>
<td>Average error</td>
<td>1.29</td>
<td>-0.14</td>
</tr>
<tr>
<td>Maximum error</td>
<td>2.34</td>
<td>-0.04</td>
</tr>
<tr>
<td>Minimum error</td>
<td>0.82</td>
<td>-0.55</td>
</tr>
</tbody>
</table>
5.0 DISCUSSION

5.1 Causes of error

The sources of error are:

- sampling and measurement
- influences of the biomass (billets and leaf)

5.1.1 Sampling and measurement errors

Prior to 1997 two prepared cane samples were collected for each rake by placing alternate samples from the fibre door into separate bins. The difference between the average ash results for each bin is a measure of the variability within a rake. The difference between ash results for the two bins as a percentage of the average of the two bins was relatively independent of ash level, this value being approximately 6.5 percent. However the confidence in this result is lower for ash greater than 4 percent due to the low number of samples. Visual observation of very dirty rakes during sampling indicated that the soil level in many of these was extremely variable. Therefore sampling errors could be very significant at high ash levels.

Because radioactive disintegration is a random event the amount of gamma radiation produced in a particular time interval is not a constant. A histogram of the cps measured over a series of constant time intervals would show a normal distribution. The standard deviation of this distribution can be described mathematically:

\[ \text{Standard Deviation} = \left( \frac{\text{counts per second}}{\text{time interval in seconds}} \right)^{1/2} \]

The difference between the actual measured value and the average value for cps is known as the counting statistics error.

From this equation, an average sized consignment that is scanned for 450 seconds would have 95 percent confidence limits of ± 0.78 at 70 cps and 1.07 at 130 cps. When expressed as a percentage of the cps less background, as used in the prediction equations, the 95% confidence limits are ± 13% at 70 cps and 1.6% at 130 cps. Therefore, the errors relative to the actual ash are highest for low specific activity and low ash consignments.

Also, the confidence limits increase as time of scanning is decreased. That is, higher errors are more probable with short rakes.

Combined sampling errors and errors in the measurement of counts per second, specific activity and tonnes per hour, do not account for the larger errors in the 1997 and 1998 data set.
5.1.2 Influences of the biomass

Subsequent to the 1998 season a thorough analysis of the data from the two years has been carried out with the aim of discovering what causes the errors and how to derive more accurate prediction equations.

The basic concept behind the measurement system is that the counts per second of gamma radiation given off by the cane supply should be proportional to the percent soil in it, the specific activity of the soil, and the amount of cane the monitor scans at any instant. The effect of any radioactivity in the biomass is considered of little consequence.

It is known that the potassium content of biomass ash is of the order of 30 percent, which is far greater than that of the soils that may range from almost zero for very sandy soils to about 4 percent for heavy clay soils. As the $^{40}$K isotope is responsible for the gamma radiation in the potassium channel, it is expected that the biomass ash would make a measurable contribution to the total counts per second and would become more significant as the percent total ash becomes lower.

For evaluation of the effect of cane or cane ash on the system it is useful to consider the following ratio that has been called the specific cps ($C_S$):

$$C_S = \frac{\Delta \text{ cps}}{(A \times S \times L)} \text{................................(5)}$$

Where $\Delta \text{ cps} = \text{change in the cps from the background value for any one of the four cps measurements}$

$A = \text{weight percent ash in the cane supply}$

$S = \text{specific activity of the soil}$

$L = \text{load of cane per unit length of the belt}$

If the basic concept were accurate, the value of $C_S$ would be constant depending only on the size of the detector and the arrangement of the measurement system. If the measurement errors for a set of data were random, which is expected, a symmetrical distribution of values of the ratio around this constant would be obtained.

If the specific activity of the biomass ash is different from that of the soil the value of $C_S$ will depend on the relative amounts and relative specific activities of soil and biomass ash. At high total ash levels the proportion of biomass ash becomes small and $C_S$ will approximate the constant. As the total ash becomes less and biomass ash becomes more significant, the deviation from the constant will progressively increase. For a given amount of ash the deviation will increase as the difference between specific activity of the two components increases. Therefore if the biomass ash has a higher specific activity than the soil, values of $C_S$ will become progressively higher at low ash and at low specific activity of soil. For specific activity of biomass ash lower than that of soil the opposite would result. Illustrations of these trends are shown in Figures 7 and 8.

5.2 Investigation of Caravan Hill soils
In order to investigate the causes for consistent over-estimation on two farms in the Caravan Hill area, twenty-one soil samples were taken from these farms and from others where the predictions were considered consistently good. The specific activities at the sampling points were first determined using the portable Eberline ESP1 gamma monitor. Counts per second values obtained from the instrument were converted to specific activity using a calibration table. The soil samples were spread out on trays and air-dried at ambient temperature for a week. The gamma radiation emitted by the dry samples was measured by placing them on the cane belt above the CANESCAN detector. They were also sent to CSIRO's low background counting facility at Clayton, Victoria. An important difference between the methodologies is that the samples varied between 3 and 5 kg for the CANESCAN measurements whereas a constant 3 kg was used at CSIRO.

The conclusions from these tests are:

- the counts per second responses of the Eberline and CANESCAN instruments are consistent;
- the Eberline provides reliable values of specific activity;
- there is nothing unusual in the gamma spectra for Caravan Hill soils to explain the overestimation of ash for this area.

Specific activity is more closely related to the cps in the uranium and thorium channels than to the cps in the potassium channel. Regression coefficients for specific activity determined by the Eberline detector and the cps data determined by CSIRO are 0.98 for the total cps, 0.39 for potassium, 0.94 for uranium, 0.93 for thorium, and 0.96 for uranium plus thorium (Figures 22 to 26). Because of the poor relationship between potassium in soil and specific activity, the use of the potassium cps for cane consignments as an indication of the contribution of the biomass ash is not very reliable. This conclusion was also reached on the basis of regression analysis.

A regression of the total CANESCAN counts per second versus the specific activity (Eberline) has a regression coefficient of 0.894. The sample weight variation of ± 1 kg around the average of 4 kg used for the CANESCAN tests can account for the additional scatter of this data compared with that of CSIRO.

### 5.3 Background variation

Prior to 1997 when diurnal cycles in predicted ash were recognised, two causes were considered to be possible. The CSIRO monitor did not have a temperature-controlled detector and it was believed that temperature variations might have been responsible for the observed pattern. The CANESCAN detector enclosure temperature is controlled at 40º C. However, some diurnal variations were still apparent in the data suggesting that the cause was probably due to background variations.

Both the CANESCAN detector and the CSIRO background detector trends exhibited diurnal variations in the gamma background. While not identical, the two instruments showed similar patterns. In general the highest values are in the middle of the night and the lowest in the middle of the day. It is believed that this is the result of atmospheric pressure variations resulting in a variable rate of release of radon from the ground.
Radioactive disintegration of this radon affects the cps measured. It should be noted that the background detector is not temperature-controlled. The shielding over the CANESCAN absorbs a significant fraction of the gamma particularly at lower energy levels. Both of these facts may influence the comparison. The variation observed with the background monitor is 4.7 to 5.7 cps. Data from the background detector will continue to be monitored in 1999 with the aim of developing a suitable method for prediction adjustment.

5.4 Storm events

Storm events, which were first identified in 1993, result in large over-predictions of soil content. With the CANESCAN instrument in place, this phenomenon has been observed and recorded in more detail. In 1998 there were quite a few events associated with the unusually wet harvest. The typical event peaks and decays over a period of approximately two hours. When a storm is preceded by a sharp drop in atmospheric pressure, there is a rapid release of radon from the ground. (Ref P J Mathew, CSIRO Minerals Division). The short half-life of radon causes an increase in the gamma radiation in the uranium channel and in the low energy range of the spectrum. The increase in the low energy range is the result of interaction of higher energy radiation with the material it passes through. Some of this, consequently, is re-emitted at lower energy levels. As the energy in the thorium channel is not affected by this, such an event is easily detected by monitoring the uranium to thorium ratio. When a storm event is identified soil predictions for payment purposes are suspended.

5.5 Conclusions on causes of error

- The general tendency to overestimate at low ash and to underestimate at high ash is primarily due to the non-linearity of the relationship between percent ash and counts per second. The equations used do not adequately describe this.

- Variation in the amount of potassium in the biomass, which is influenced by the amount of leaf material is the major cause of the non-linearity.

- In dry weather the most probable cause of increased over-estimation is the existence of a high specific activity film on the cane. This is more significant at low ash levels and ash levels tend to be lower during dry weather.

- In wet weather cane tends to be dirtier. At ash levels significantly above the average there is a tendency to underestimate due to the non-linearity of the system. Also at high ash levels the variability of soil within a rake can lead to the prepared cane sample being not representative.
5.6 Prediction equation development for 1999 season

The analysis of the causes of error in the 1997 and 1998 data and the development of theoretical trend models showing the variation in non-linearity with specific activity have led to a method of deriving a new prediction procedure for use in 1999. This procedure can be divided as follows:

- Derive an equation for readily identifiable high ash consignments
- Derive equations for the remaining consignments based on ranges of specific activity
- Specify a minimum value for ash in prepared cane
- Apply empirical corrections to predictions for farms with a consistent bias
- Derive equations to use when juice properties are not available

5.6.1 Equation for high ash consignments

Data analysis has shown that the selection of samples where $Fn_1$ is 0.55 or greater will produce a subset that has ash values of four percent or greater. The relative effect of the biomass for these is small and a separate equation reduces the tendency to underestimate at this high ash level. Because the non-linearity of the system is not large at higher specific activity it has been found that it is necessary only to apply a separate equation when the specific activity (S) is less than 70.

Therefore when $S$ is less than 70 and $Fn_1$ is not less than 0.55 Equation 6 is used

\[
\text{Ash} = 0.538 + 0.133 \times \text{cps} - 0.1029 \times S - 0.887 \times \text{Load} - 0.230 \times Fn_7 \\
+ 0.952 \times (1/Fn_9).................................................................................................................... (6)
\]

The terms $Fn_7$ and $Fn_9$ are defined in section 4.2

5.6.2 Equations for lower ash consignments

For the lower ash levels ($Fn_1 < 0.55$) the non-linearity becomes more significant particularly at low specific activities. It has been found that improved predictions can be obtained by adjusting the specific activity to compensate for this. This adjustment is needed only for lower specific activities where the non-linearity is greater.

Using the plot of $CS$ (specific cps for the total cps) versus specific activity (Figure 8), an equation was established to describe the general trend for specific activities of 60 and lower.

\[
CS = 2.906E-05 \times S^2 - 3.278E-03 \times S + 0.1343 ................................................................. (7)
\]

An adjusted specific activity is then calculated.

\[
\text{Adjusted specific activity} = \left( \frac{CS}{\text{Ave } CS} \right) \times S......................................................... (8)
\]

An adjusted $Fn_1$ is calculated using the adjusted specific activity.

\[
\text{Adjusted } Fn_1 = \Delta \text{ Total cps} / \text{Adjusted specific activity}.............................. (9)
\]
Equations are then derived for different ranges of specific activity (unadjusted) applying the adjusted values of Fn1 and adjusted specific activity. By trial and error it has been found that it is necessary to use three specific activity ranges.

If S is 70 or greater use Equation 10

If S is 50 to 59 and Fn1 is less than 0.55 use Equation 11

If S is less than 50 and Fn1 is less than 0.55 use Equation 12

The constants, variables and coefficients applied to each of the variables in equations 10, 11 and 12 are shown below in Table 5.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Constants &amp; coefficients for variables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Equation 10</td>
</tr>
<tr>
<td>Constant</td>
<td>2.722</td>
</tr>
<tr>
<td>Adjusted Fn1</td>
<td>10.159</td>
</tr>
<tr>
<td>Adjusted Specific Activity</td>
<td>0.0184</td>
</tr>
<tr>
<td>Fn3</td>
<td>-0.0884</td>
</tr>
<tr>
<td>1 / Load</td>
<td>3.884</td>
</tr>
<tr>
<td>Brix of FEJ</td>
<td>-0.1256</td>
</tr>
<tr>
<td>Conductivity of FEJ</td>
<td>-0.4176</td>
</tr>
<tr>
<td>Impurities in FEJ / Brix</td>
<td>-3.123</td>
</tr>
<tr>
<td>Fn10</td>
<td>-27.065</td>
</tr>
<tr>
<td>DU / DT</td>
<td>-0.482</td>
</tr>
</tbody>
</table>

Where:  
Fn10 = (Δ cps for thorium channel)/(Δ Total cps)  
DU/DT = (cps for uranium channel – 0.3)/(cps for thorium channel –0.3)

The reason for calculating the ratio in this manner is to avoid divisors of zero that would occur if the empty belt background were subtracted.

The first six variables correlate strongly over the total specific activity range. The last three are not as statistically significant.

5.6.3 Minimum value of ash in prepared cane

The results from ashing of cane from 1993 to 1997 show that, realistically, it is improbable that a cane consignment would have an ash content below 0.5 percent. This is supported by ash data for clean billets and leaf.

If the prediction using equations 6, 10, 11 and 12 is below 0.5 percent a value of 0.5 is applied to the consignment.
5.6.4 Empirical corrections for farms with a consistent bias

A consistently high bias in the ash predictions has been noted for some farms. Although Equations 10 to 12 have reduced this relative to previously applied equations, it has been found that making empirical corrections can make improvements. Four farms including the two Caravan Hill farms have been identified and the following corrections are made.

Farm ‘A’

Adjusted prediction = prediction – \((1.114 - 0.0123 \times S)\).......................... (13)

Farm ‘B’

Adjusted prediction = prediction – \((0.022 + 3.042 \times Fn1)\).......................... (14)

Farm ‘C’

Adjusted prediction = prediction – \((5.576 - 1.371 \times \text{conductivity})\).............. (15)

Farm ‘D’

Adjusted prediction = prediction – \((1.071 + 0.805 \times \text{conductivity})\)............. (16)

5.6.5 Equations when juice properties are not available

When cane payment samples are small or are missed for other reasons, brix, pol and conductivity are not always available. Ash predictions are still required for use by mill personnel. Alternative equations have been developed for use when any one or all of these variables is missing. When these variables are omitted there is some sacrifice of accuracy.

For the alternatives to Equation 10, the variables used and their coefficients are summarised in Table 6 for the three cases: conductivity not available, brix and pol not available and brix, pol and conductivity not available. Similar summaries are given in Table 7 for alternatives to Equation 11 and in Table 8 for alternatives to Equation 12.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Constants &amp; coefficients for variables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No conductivity</td>
</tr>
<tr>
<td>Constant</td>
<td>1.951</td>
</tr>
<tr>
<td>Adjusted Fn1</td>
<td>8.813</td>
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<tr>
<td>Adjusted Specific Activity</td>
<td>0.00798</td>
</tr>
<tr>
<td>Fn3</td>
<td></td>
</tr>
<tr>
<td>1 / Load</td>
<td>3.198</td>
</tr>
<tr>
<td>Brix of FEJ</td>
<td>-0.1287</td>
</tr>
<tr>
<td>Conductivity of FEJ</td>
<td></td>
</tr>
<tr>
<td>DU / DT</td>
<td>-0.480</td>
</tr>
<tr>
<td>1/Fn7</td>
<td>-1.841</td>
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</table>
Table 7

<table>
<thead>
<tr>
<th>Variable</th>
<th>Constants &amp; coefficients for variables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No conductivity</td>
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<td>Adjusted Fn1</td>
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<td>-0.0243</td>
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<tr>
<td>1 / Load</td>
<td>2.848</td>
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<tr>
<td>Brix of FEJ</td>
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</tr>
<tr>
<td>Conductivity of FEJ</td>
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</tr>
<tr>
<td>Impurities in FEJ / Brix</td>
<td></td>
</tr>
<tr>
<td>DU / DT</td>
<td>-0.528</td>
</tr>
<tr>
<td>1/Fn7</td>
<td>-1.767</td>
</tr>
</tbody>
</table>

Table 8

<table>
<thead>
<tr>
<th>Variable</th>
<th>Constants &amp; coefficients for variables</th>
</tr>
</thead>
<tbody>
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<td>No conductivity</td>
</tr>
<tr>
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<tr>
<td>Adjusted Fn1</td>
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<td>0.0099</td>
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<td>Fn3</td>
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</tr>
<tr>
<td>1 / Load</td>
<td>2.003</td>
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<td>Brix of FEJ</td>
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</tr>
<tr>
<td>Conductivity of FEJ</td>
<td></td>
</tr>
<tr>
<td>DU / DT</td>
<td>-0.326</td>
</tr>
</tbody>
</table>

6.0 RECOMMENDATIONS

An ongoing audit is required to check both the performance of the latest prediction equations and the performance of the instrument.

Cane properties should be included in the prediction equations. This is necessary to reduce the prediction errors.

As new data becomes available from audit samples, further regression analysis should be carried out with the objective of improving prediction accuracy. Non linear regressions should be explored.
6.1 Arrangement and installation at other mills

For a new installation it would be advantageous to maximise the amount of shielding in order to reduce the background radiation. This would have two effects. It would reduce the counting statistics error in the cps measurement due to the lower value and would reduce the size of the variation in the background cps. Money spent on a background monitor would be better spent on shielding.

As many samples are required to develop calibration equations, the optimum shielding should be installed at the initial installation. A new calibration would be required if the shielding were changed.

If possible the instrument should be installed to monitor prepared cane, as the soil should be more uniformly distributed in this compared with billets.

7.0 PUBLICATIONS

FIGURES
FIGURE 1  TIME SERIES PLOT OF PREDICTION ERROR
FIGURE 2  PREDICTION ERROR vs PERCENT ASH FOR 1997 AND 1998
FIGURE 3  PREDICTION ERROR vs SPECIFIC ACTIVITY for 1997 and 1998
FIGURE 4  ERROR vs PERCENT ASH - 1999 EQUATIONS
FIGURE 5  TIME SERIES PLOT OF ERROR  - 1999 TRIALS
FIGURE 6  TIME SERIES PLOT OF RELATIVE ERROR - 1999 TRIALS
FIGURE 7 THEORETICAL TRENDS FOR SPECIFIC CPS vs PERCENT ASH - WITH SPECIFIC ACTIVITY OF CANE ASH HIGHER, LOWER AND SAME AS SOIL
FIGURE 8  THEORETICAL TRENDS FOR SPECIFIC CPS vs PERCENT ASH FOR LOW AND HIGH SPECIFIC ACTIVITY SOILS
FIGURE 10  SPECIFIC CPS FOR TOTAL CPS vs SPECIFIC ACTIVITY
FIGURE 11    RELATIVE PREDICTION vs SPECIFIC CPS FOR TOTAL COUNT

$R^2 = 0.88$
FIGURE 12  SPECIFIC CPS FOR POTASSIUM CHANNEL vs PERCENT ASH
FIGURE 13 SPECIFIC CPS FOR POTASSIUM CHANNEL vs SPECIFIC ACTIVITY
FIGURE 14  SPECIFIC CPS FOR URANIUM CHANNEL vs PERCENT ASH
FIGURE 15 SPECIFIC CPS FOR URANIUM CHANNEL vs SPECIFIC ACTIVITY
FIGURE 16  SPECIFIC CPS FOR THORIUM CHANNEL vs PERCENT ASH
FIGURE 17  SPECIFIC CPS FOR THORIUM CHANNEL vs SPECIFIC ACTIVITY
FIGURE 18  COMPARISON OF 1997 AND 1998 SPECIFIC CPS TRENDS FOR TOTAL CPS

A scatter plot comparing specific CPS trends for total CPS between 1997 and 1998. The x-axis represents percent ash, ranging from 0 to 7, and the y-axis represents specific CPS, ranging from 0 to 0.07. The data points are differentiated by year: circles for 1997 data and triangles for 1998 data.
FIGURE 19  COMPARISON OF 1997 & 1998 SPECIFIC CPS TRENDS FOR POTASSIUM CHANNEL
FIGURE 20  COMPARISON OF 1997 & 1998 SPECIFIC CPS TRENDS FOR URANIUM CHANNEL

- SPECIFIC CPS
- PERCENT ASH

▲ 1997 DATA
● 1998 DATA
FIGURE 21  COMPARISON OF 1997 AND 1998 SPECIFIC CPS TRENDS FOR THORIUM CHANNEL

![Graph showing the comparison of 1997 and 1998 specific CPS trends for thorium channel. The x-axis represents percent ash, ranging from 0 to 7, and the y-axis represents specific CPS, ranging from 0.0003 to 0.0008. The graph includes data points for 1997 (▲) and 1998 (○).]
FIGURE 22 TOTAL CPS FOR SOIL SAMPLES (CSIRO DATA) vs SPECIFIC ACTIVITY

$R^2 = 0.9801$
FIGURE 23  POTASSIUM CHANNEL CPS FOR SOIL SAMPLES (CSIRO DATA) vs SPECIFIC ACTIVITY

\[ R^2 = 0.3902 \]
FIGURE 24  URANIUM CHANNEL CPS FOR SOIL SAMPLES (CSIRO DATA) vs SPECIFIC ACTIVITY

R² = 0.942
FIGURE 25  THORIUM CHANNEL CPS FOR SOIL SAMPLES (CSIRO) vs SPECIFIC ACTIVITY

$R^2 = 0.9269$
FIGURE 26  URANIUM + THORIUM CPS FOR SOIL SAMPLES (CSIRO DATA) vs SPECIFIC ACTIVITY

$R^2 = 0.9583$