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Feature Paper

Reassessment of the grades of the Adelaide model logging pits

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International efforts made in the early 1980s to cross-calibrate the grades of model pits used in the calibration of total-count gamma-ray logging tools for uranium were never applied to bring the Australian, Canadian and USA pits into agreement. Recent studies on calibration revealed problems with the Australian pits and data from the 1980 studies has been re-evaluated to give new grades for the Adelaide pits of 0.210, 0.983, 0.051 and 0.18 eU_3O_8% for pits AM1, 2, 3 and 7, respectively. These changes ensure the four pits are in relative agreement with logging results and gamma-ray transport modelling. The absolute grade is more difficult to assign definitely but indications are that AM1, through being twice sampled by coring and analysis, is more likely to be correct than pits whose grades are solely based on analysis of poorly handled samples. The changes in the grades actually have little effect on the grades in U deposits determined using the Adelaide model pits for calibration as the error with AM2 acted as a compensation for the Z-effect in that pit.

Keywords: assigned grades, calibration, gamma-ray, logging, model pits, uranium.

Introduction

Total-count logging probes are used by uranium (U) miners and explorers to assist with ore estimates. The theory of the operation of such probes was established in the 1960s (Dodd and Eschliman, 1971). The relationship between the U grade in a thick zone in a model pit to the count-rate in a field drillhole, for U contents below a few percent, as given by George (1982b) is

$$G_d = K\ F_m\ F_z\ F_w\ F_c\ F_d\ r \qquad (1)$$

where G_d = dry grade commonly expressed as weight-percent eU_3O_8,
K = a constant of proportionality, determined at a calibration facility,
F_m = Moisture Factor to correct for differences in formation water (100 – % water in calibration model)/(100 – % water in formation),
F_z = Z-effect[1] Factor to correct for the presence of U itself, which is a function also of R,
F_w = Water Factor for differences in the fluid between test-pit and field drillhole,
F_c = Casing Factor to correct for hole rod or casing material,
F_d = Dead-time Factor, also a function of r, and
r = Observed count-rate.

As indicated by the factor K, the existence of a set of model pits in which to perform calibration is essential for the quantitative use of gamma-ray logging. In Australia such a set of pits was constructed in the late 1970s in Adelaide and is now maintained and run by S.A. Department for Water. The design of the AM2 pit is shown in Figure 1. There are four pits suitable for calibration of total count tools as detailed in Table 1.

The assigned grades in Table 1 are based on laboratory analyses (Wenk and Dickson, 1981). In the early 1980s, questions were raised about the grades in these pits not being correct and two groups, one from Canada (Bristow *et al.*, 1982) and one from the USA (George, 1982b), brought probes to Adelaide and cross-calibrated the Adelaide pits against their own. These results were presented at an OECD/NEA meeting in Paris in 1982 and published in the conference proceedings. But for unknown reasons there was no resolution to the conflicts that were apparent in the different grade estimates.

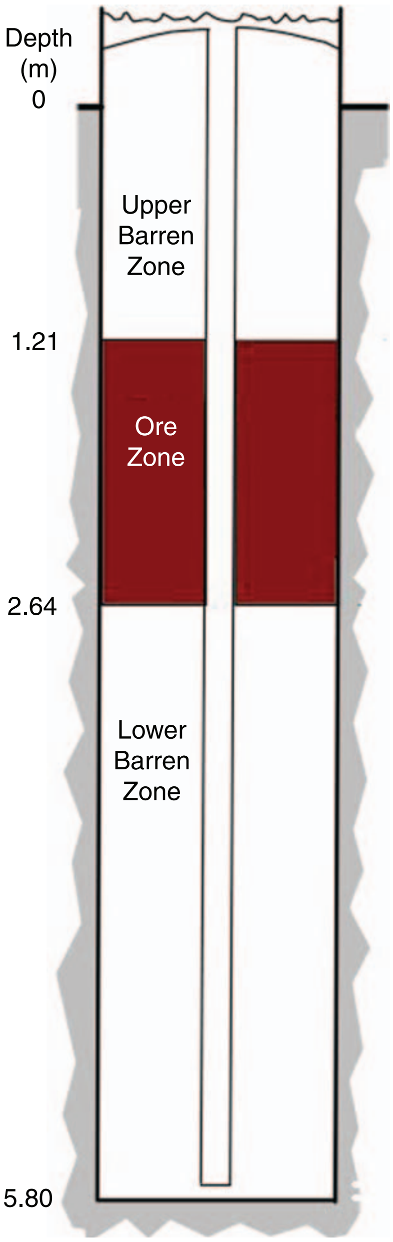

Fig. 1. *Design of the AM2 pit at Adelaide.*

[1]The Z-effect refers to the increasing adsorption of low-energy gamma-rays (<600 keV) due to the increased photoelectric adsorption of higher Z elements, such as U itself.

Table 1. Data for Adelaide pits AM1, AM2, AM3 and AM7

	AM1	AM2	AM3	AM7
Assigned grade (%eU_3O_8)	0.209 ± 0.006	0.920 ± 0.018	0.054 ± 0.002	0.17
Diameter (m)	1.22	1.22	1.22	2.16
Ore-zone thickness (m)	1.41	1.43	1.43	1.68
Porosity %	17	19	18	23.4
Wet density ($g.cm^{-3}$)	2.31	2.33	2.35	2.21

More recently, studies using Monte-Carlo gamma-ray transport codes to derive correction factors for different logging scenarios revealed that a determination of F_z from data collected in the AM pits did not give consistent values. This identified a need to revisit the data of the cross-calibration studies to determine if a consistent set of grades could be assigned to these pits.

The George (1982) Study

In 1981, Dr D.C. George of Bendix Field Engineering Corporation undertook an international cross-calibration of total-count logging pits in Australia and the USA. His methodology essentially used equation (2) recast as the ratio of two pits, that is:

$$G_x = G_s F_{zx} (F_{mx} R_x/(F_{ms} R_s))/F_{zs} \quad (2)$$

where subscript s = standard pit and x = unknown. R_s (= $F_d r$) are dead-time corrected count-rates. Calibration was done with the holes dry so no other corrections were necessary but the formation moisture, F_m, correction was included.

A report was initially issued (George, 1982a) in which the grades of the pits were determined as 0.254, 1.186 and 0.620 eU_3O_8% for pits AM1, 2 and 3, respectively. These grades were calculated relative to USDOE pit N3, which was assigned a grade of 0.240 eU_3O_8%. It was acknowledged that this pit was itself at that time undergoing revision of its grade. All these grades are stated to be 'dry-weight basis'.

George revised his analysis and presented his results at the 1982 OECD/NEA conference (George, 1982b), but although all the data was presented, the calculations for the AM pits were not explicitly made. Those calculations are presented in Table 2.

These results showed the grade of N3 decreased to 0.218% eU_3O_8 while the grades of AM1 and AM3 were barely changed from the assigned values (Table 1). AM2 was increased to 1.02%eU_3O_8, a 10.5% increase. This increase in grade for AM2 actually has little or no effect on calculated *in situ* grades because the low value for AM2 relative to both AM1 and AM3 acts as a self-correction for the Z-effect (as shown below).

Table 2. Recalculation of AM grade using data and methodology outlined in George (1982b) where R_{oc} is dead-time and Z-effect corrected count-rate

	N3	AM1	AM2	AM3
Counts	24088	25612	118957	6227
Fz	1.050	1.054	1.250	1.013
R	22926.6	24303.0	95152.9	6146.5
Moisture %	13.2	7.4	8.1	7.7
R_{oc}	27751.2	27646.6	129469.5	6743.5
Grade	0.218	0.217	1.016	0.053

The Bristow *et al.* (1982) study

Members of the Canadian Geological Survey also visited Adelaide around the same time to undertake a comparison of BU6 (the primary Canadian model pit) with N3 and AM1 (Bristow *et al.*, 1982). Their results were also reported at the 1982 OECD/NEA conference and indicated grades of 0.116, 0.2184 and 0.2216%eU_3O_8, for BU6, N3 and AM1, respectively, using water-filled holes. Thus, they obtained the same grade for N3 as George (1982b, Table 2) but a higher value for AM1. Although AM2 and AM3 were also logged, the data for those were not presented.

A final adjustment or not?

Efforts continued in the USA after the 1982 conference to standardise their model pit collection and a year later George *et al.* (1983) reported results from a cross-calibration involving 45 pits. The results and full details of the pits are given in Leino *et al.* (1994). This work adjusted the grade of N3 to 654±23 pCi/g(Ra^{226}), which equates to 0.231 ± 0.008%eU_3O_8 and implies that the grades of the Australian AM pits have to be increased by another 6.0%.

But should this change be applied? The difficulty in accepting the grades of the USA and Canadian pits as correct is that their grades are based on samples taken at the time of construction. In both cases very non-standard methods compared with concrete-industry standards were used. For the USA, 1.9 L samples were placed in ice-cream cartons and allowed to air dry. George *et al.* (1983) recognised that this was not an optimum procedure and stated 'if additional samples are collected (say by coring), or if additional information becomes available on the present unknowns (the difference, if any, between the concrete in the samples … and the concrete in-situ in the models), then the assignments could change'. As this quote indentifies, the sampling technique used by the USA could give biased results as the concrete in the sample containers was not cured properly and may contain far less water of crystallisation than a properly cured concrete, as in the pits. This sampling methodology could have introduced a systematic error with all the results being high.

This problem was examined using a batch of concrete that was sampled in three different ways (Dickson, 1983). The methods were a sample of wet mix sealed in a 300 mL can (the Canadian method), a 2 kg mix placed in an open 4 L plastic container (the USA method), and a 1.5 kg sample placed in a steel circular mould, 104 mm diameter and 280 mm long. After 24 h curing the mould was removed and the concrete cylinders kept over a water bath at 22°C for 1 month (the concrete industry method). Analytical results obtained for U for the three methods were 277 ± 15, 254 ± 6 and 257 ± 11%eU_3O_8, respectively, which clearly suggests that the pit grades for the Canadian pits could be over-estimated relative to a properly cured concrete.

The most reliable method for analysing the U grade of the pits would be to use the methods familiar to the exploration and mining industry, i.e. drill a core from the pits and analyse those samples. This was how the original grades for the AM pits were obtained. In 1983, pit AM1 was re-drilled with a core removed from the edge. The original samples were re-analysed and gave

$0.210 \pm 0.0.008\%eU_3O_8$. The new samples gave almost the same result, $0.212 \pm 0.008\%eU_3O_8$. On this basis, AM1 should be taken as containing $0.210\%eU_3O_8$. Both AM2 and AM3 require that their grade also be adjusted to 0.983 and $0.051\%eU_3O_8$, respectively, based on the logging results in Table 1.

The astute reader will notice that the earlier claim that drilling, coring and analysing is the optimum sampling method is not supported by the need to adjust grades for both AM2 and AM3, grades which were originally based on coring and analysis. The same goes for AM7 (see below) as well. Why AM2 should require such a large change is puzzling and no explanation is offered at this time. But it does suggest the sampling and analysing of these concretes is not well defined and doubts must remain over the grade assignments of all pits. An independent method of grading the pits not involving sampling would be most welcome.

Confirmation of grade change for Adelaide pits

A confirmation of the relative changes in grades for the AM pits can be obtained by determination of F_Z, using both data collected in the model pits and through calculations using Monte-Carlo transport codes. This latter method is described in Dickson and Beckitt (unpublished report) and involves the use of the code GEANT. A geometry is established modelling that of the calibration setup in the AM pits and spectra of the gamma-ray radiation received in a detector within the pit are calculated. Total-counts above a selected threshold may then be obtained.

Values for F_Z may be calculated from the ratio of the grades and counts for two pits using:

$$F_{ZH}=(G_H\, F_{ZL}\, R_L)/(G_L\, R_H) \qquad (3)$$

where subscripts H and L refer to high and low grade pits, Rs are dead-time corrected count-rates and the two pits are assumed equal in all other aspects. For a very low grade pit, e.g. AM3, F_{ZL} can be assumed as 1 and F_{ZH} readily calculated. Table 3 illustrates some F_Z data determined for AM1 and AM2 with AM3 as reference with a variety of detectors.

The set 1 data in Table 3 was measured by George (1982a) and shows that the F_Z value for AM2 with the original grades was below 1, but with the new grades the value 1.24 is very close to the measured value of 1.23. For all other probes, Table 3 shows that, with only one exception (set 4), there is little difference in F_z between AM1 and AM2 with the original grades. With the adjusted grades, the F_Z values for AM2 obtained with seven detectors are now all greater than the values for AM1 and are of the expected magnitude.

Table 3. Values of the Z-effect correction factor FZ for a variety of detector types. All detectors are unshielded. Detector sizes are length x diameter in cm

Set	AM1	AM2	AM1	AM2	AM2 (modelling)	Detector
	OLD grades		*NEW grades*			
1	1.02	0.91	1.04	1.24	–	NaI, 3.9 x 3.8
2	1.00	1.06	1.06	1.19	1.21	NaI, 4.4 x 1.25
3	1.00	1.05	1.06	1.19	1.21	NaI, 4.4 x 1.25
4	0.99	1.15	1.05	1.30	–	NaI, 5.0 x 2.5
5	0.98	1.03	1.03	1.20	–	NaI, 5.0 x 2.5
6	0.97	1.05	1.03	1.18	1.18	BrilLanCe 2.5 x 2.5
7	0.97	1.05	1.03	1.21	1.18	BrilLanCe 10 x 2.5

Values of F_Z for AM2 were determined by modelling for four of the detectors. The modelled values (Table 3) are dependent on the setting in the detectors of a low-energy threshold, which is set to prevent noise from the detector entering the electronics. This setting is generally low but unknown and the values shown are calculated with estimates of the thresholds. The agreement of the F_Z values between those calculated using the new grade value and modelled for AM2 gives a degree of confidence that the new grade values are relatively correct. Unfortunately this analysis only applies to the relative grades because the F_Z calculation involves a ratio of grades and cannot be used to justify the absolute values of the grades. For the moment our confidence in these grade reassignments must rest on the good agreement of the AM1 grades of the two sets of cored samples.

Grade for pit AM7

Pit AM7 is larger in diameter than pits AM1–AM3 and accommodates five drillholes of sizes BQ, NQ, PQ, HQ and 108 mm (same as AM1–AM3) to enable water factor corrections to be determined. The grade of this pit is assigned $0.17\%U_3O_8$. This grade requires adjusting in line with the other pits.

Some logging data made available for this study (Table 4) was used to calculate the grade of AM7 with the assumption that F_Z and formation moisture for AM1 and AM7 were the same and using the moisture data in Table 1. This gave a new grade value of $0.18\%U_3O_8$ (Table 4). Further work is recommended to refine this value, which should include modelling to take into account the larger diameter but lower density of the U-zone in this pit, relative to the other three.

Conclusion

The grades for the total count calibration pits in Adelaide should be changed to 0.210, 0.983, 0.051 and 0.018 $eU_3O_8\%$ for pits AM1, 2, 3 and 7, respectively. This change ensures the four pits are in relative agreement with logging results and gamma-ray transport modelling. The absolute grades are more difficult to confirm but indications are that through being twice sampled by coring and analysis, AM1 is more likely to be correct than those pits whose grades are solely based on analysis of poorly handled samples. The recommended changes in the grades actually have little effect on the grades in U deposits determined using the Adelaide model pits for calibration as the error with AM2 compensated the Z-effect in that pit. These changes leave the Australian pits some 6% lower than the USA and Canadian pits and there is clearly a need to determine a method to analyse the true grades of these concrete pits before this issue can be finally resolved.

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Table 4. Data used to obtain grade for AM7

Pit	AM1	AM2	AM3	AM7
Grade ($\%U_3O_8$)	0.210	0.983	0.051	0.190
Counts (cps)	9300	37507	2338	8425
Fz	1.033	1.199	1	1.033

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