DELTA EPSILON INSTRUMENTS, INC.
2591 B ¾ Rd., Grand Junction, Colorado 81503 USA Tel(970)243-4072 sales@deltaepsilon.com

APPLICATION NOTE 2
A SIMPLIFIED METHOD FOR CALIBRATING GROSS-GAMMA LOGGING PROBES

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prepared by
Robert D. Wilson for
Delta Epsilon Instruments, Inc.

Introduction:

There has been resurgence in borehole logging for uranium, both in the US and abroad. Instrument calibration has become an issue of concern, especially since many years have elapsed since the construction and evaluation of available calibration facilities, and because federal support for uranium logging calibration, both in the US and Canada, has virtually disappeared.

There has been confusion about the best method of calibration when logging for uranium concentration in a particular environment. There are several reasons for this confusion:

1. The historically accepted methods are in many ways outdated.
2. High grade U deposits require a different calibration approach.

This application note presents a relatively simple procedure for calibrating gross-gamma probes. The calibration will be applicable to uranium grades from 0 to the highest model grade of about 2% U_3O_8.

Calibration Facilities and Grade Assignment :

There are U logging probe calibration models in several countries. We restrict this discussion to the models in the US.

US Calibration Models.

The most extensive US models are located in Grand Junction, CO. Other models are located in Casper, WY, George West, TX and Grants, NM. There are models for calibrating both spectral gamma (KUT) probes and gross-gamma probes at these sites. The models at each site that are recommended for gross-gamma calibration are listed in Table 1, along with U_3O_8 grade assignments (George et al., 1983, Table ES-1).

Table 1. US calibration model grade assignments.

Model Location	Model Designation	Assigned Dry Grade (%U_3O_8)	Wet In-situ Grade (%U_3O_8)**
Grand Junction	U1	2.636	2.354
Grand Junction	U2	1.229	1.050
Grand Junction	U3	0.4516	0.3827
Grand Junction	N3	0.2311	0.2010
Grand Junction	U	0.0557	0.0489
Grand Junction	BA	0.0221	0.0204
Grants, NM	GH	1.995*	1.797
Grants, NM	GBB	0.3114	0.2857
Grants, NM	GBU	0.0591	0.05225
Grants, NM	GBA	0.0229	0.0211
Casper, WY	CH	2.345*	2.120
Casper, WY	CBB	0.3047	0.2793
Casper, WY	CBU	0.0597	0.0530
Casper, WY	CBA	0.0229	0.0211
George West, TX	TH	2.039*	1.756
George West, TX	TBB	0.2969	0.2736
George West, TX	TBU	0.0595	0.0525
George West, TX	TBA	0.02184	0.0202

*Grades based on logging comparisons to other models. Laboratory sample assays unavailable.
**Computed from dry grades with adjustment for published moisture content for each model.

The grades presented in Table 1 typically have reported uncertainties of about 1.5% (one standard deviation), except for the highest grades at all sites, where uncertainty is reported at about 3.1%. The grades are weight percentages U_3O_8 based on the dry bulk density of material comprising each model. Since field logs, and data taken in the models, correspond to the in-situ material, with moisture in place, the grades need to be corrected for the moisture removed by the sample assay process. The last column contains the grades adjusted for moisture content as reported by George (George et al., 1983). These moisture adjusted grades should be used in the calibration of logging probes. Then, field logs will give in-situ wet bulk uranium grades, regardless of their moisture content.

The calibration:

The simplified procedure presented here does not attempt to determine the dead time of the logging system, or the Z-effect that occurs at high grades for unfiltered probes. Rather, the method consists simply of measuring probe response at the middle of the ore zone for each of a set of models that cover the grade range of interest, and directly relating that response to reported grade:

$$\mathbf{G} = \boldsymbol{f}\,(\mathbf{R})$$

where,

- **R** is the measured probe response in counts/sec (cps),
- **G** is the assigned wet in-situ U_3O_8 grade in percent (%), and
- ***f*** **(R)** is a polynomial fit to the plot of G versus R.

This method also avoids the use of the relation G x (thickness) = k x A where A is the area under the plot of response versus depth within the model, and k is a proportionality that is constant if proper account is taken of dead time and Z-effect. But this method is more complicated than necessary, requiring a precision log of the calibration model. The historic method of determining dead-time (Duray, 1976) from logs in two models of differing grade (say N3 and U2) is problematic in that there is no simple way to separate the effects of dead-time and Z-effect since both are count rate dependent.

The polynomial fit to the calibration data results in a cubic equation relating log data in counts/sec to uranium grade. Nominally, a third order fit is done that has the form:

$$G = a1 \times (\log c/s) + a2 \times (\log c/s)^2 + a3 \times (\log c/s)^3.$$

The raw logging data are then processed by substituting count rates in this equation. The fit to the calibration data is done with the trend line feature of Microsoft Excel, with a constraint that the fit pass through the origin (gives zero grade for zero count rate). The log processing is easily done in an Excel worksheet using its equation calculation feature. An example is included later to illustrate the method.

Only if the ore zone thickness is less than the sampling volume of the logging tool, is it necessary to perform the calibration based on an area A measurement. The historical “k factor” used for calibrating probes, as developed in the 1960’s (Scott et al., 1961) contains a length unit that depends on the sampling interval used for logging and was meant to be used for removing the smearing effect that the gamma logging has on the actual grade versus depth. It has been shown that such removal is not necessary to obtain correct grade x thickness from logging data (Scott et al., 1961). If actual grade versus depth is needed, the processed log must be deconvolved, either with the iterative GAMLOG method (Scott, 1963) or the inverse filter method (Conaway, 1978).

Procedures:

1. **Insure stable probe operation** by use of a check source that is placed on the probe at the detector location, in a reproducible position. Count rates should be taken before and after calibration. For such measurements, it must first be determined that background is negligible. If not, the stability check should be done with a shield around the detector and source. At least 10,000 counts should be recorded to insure at least 1% precision in the measurement. If no such source is available, a log scan should be taken in one particular borehole model before and after calibration of the probe. The area under the scan for a particular depth range should be in agreement for the two measurements, within the statistics of the total counts. A similar procedure should be used when logging in the field to ensure that the probe has not changed since calibration.
2. **Calibration data.** For a particular site, at least four of the models listed in Table 1 should in turn be logged in a scan mode to locate the ore zone midpoint. Then data are recorded at three locations: the midzone, and the midzone +/- 6 inches. Counts of at least 10,000 should be accumulated at each location to ensure statistical precision of 1% or better. If the three counts are repeatable according to this test, then take the average of the three counts. This is the measured response for the grade of that model. Repeat this process for remaining models selected for the site from Table 1.
3. **Calibration equation.** The wet in-situ grade (last column, Table 1) is then plotted versus count rate. The plotted points are fit with a 3rd order polynomial. The fitting equation should be constrained to pass through the origin (i.e., gives zero grade for zero counts/sec). Fit the data with a cubic polynomial using the "Trend Line" feature of Excel. The data points should fall close to the fitted curve, giving a correlation coefficient very close to unity. The option requiring the fit to pass through the origin should be checked. If any of the points deviate significantly from the fitted curve, the data should be examined, and if necessary, the model measurement should be repeated. The coefficients of this polynomial are then used to process count rates from field logs to give uranium grade.
4. **Borehole water correction.** The measurements specified in step 2 should be made with dry boreholes. This ensures that there will be no borehole size correction for field logs, as long as the field boreholes are dry. If below the water table, then a water correction must be made to the logs. Borehole water corrections must be made based on measurements in the water factor model in Grand Junction, CO. The so-called "water factor" curve will be the same for all probes of a given design. That is, for a given detector, filter, and probe size. This curve is usually supplied by the manufacturer. If not, the system should be brought to Grand Junction for a one-time water factor measurement. Field logs are corrected by multiplying the logged grade by the water factor for the borehole diameter as determined by a caliper log, or by drill bit size. Remember, this correction is required only if logging in water-filled boreholes.
5. **Casing correction.** If the logged borehole is cased, then casing attenuation corrections must be made to the logging data. These can be very large corrections, and so must be accurately made. The Grand Junction site has iron sleeves that can be used for measuring the casing correction as function of iron thickness for a given probe system.

Discussion and caveats:

The calibration equation that results from this method should be applied only for count rates, or grades, that fall within the range of the calibration models, from 0 to about 2% U_3O_8. For higher grades, the response is not defined by the polynomial fit.

The calibration is appropriate only for thick ore zone, zones with thickness greater than about 2 feet. As zone thickness decreases below 2 feet, the maximum probe response gradually decreases, for a given zone grade. The probe system is in reality smearing the count rate response over a larger zone that is characteristic of the gamma energies, borehole size and fluid condition, ore and barren zone density, detector length, and other parameters. Fortunately, however, the area under this response curve is always proportional to the thin zone grade times its thickness (Scott et al., 1961). Because of the smearing effect, this calibration procedure should not be applied to calibration models with zone thickness less than about 3 feet. Failure to meet this requirement will result in a faulty calibration. This condition can always be insured by requiring the log scan to have a flat portion of about 1 ft thickness at midzone

This calibration method, based on in-situ uranium concentration, with moisture in place, will produce nearly correct in-situ field concentrations from logs, regardless of moisture content in the field (Wilson and Stromswold, 1981). If dry bulk concentrations are desired, the log analyst must know the moisture content of the logged formation, and an appropriate correction applied. The moisture content is normally obtained using a calibrated neutron-neutron probe in combination with a gamma-gamma density probe.

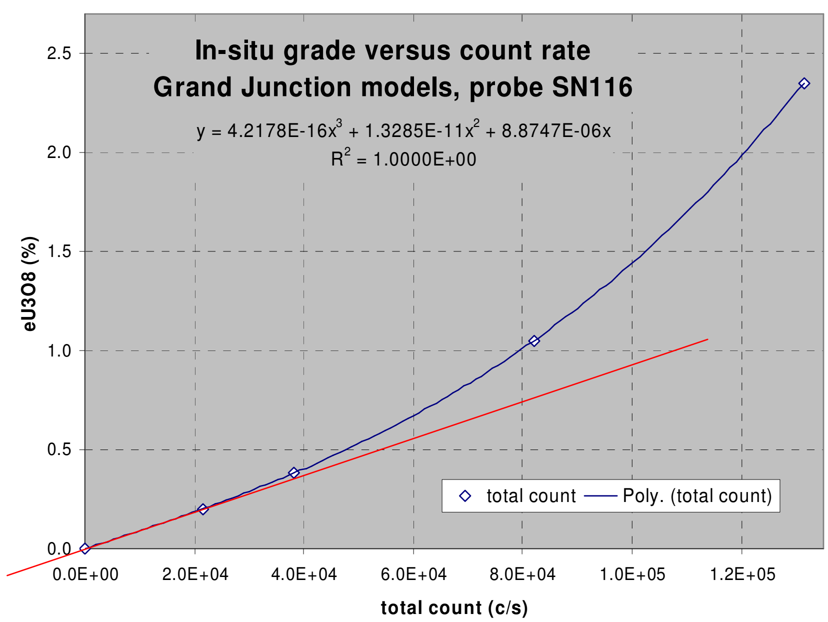
The use of this calibration with field logs assumes that the ore body is in radioactive equilibrium. That is, the gamma-emitting daughter products that are the basis of the gamma log must be in equilibrium with the uranium parent. If this is not the case, then a correction must be made for disequilibrium. This correction requires a chemical and a gamma assay of drill core samples.

Example Caliarbtion :

Data taken with a Delta Epsilon Instruments Corporation gross gamma logging probe is given in the table below. The midzone counts/sec were measured for four Grand Junction models, and the grades from Table 1 are repeated here. The plot of grade versus count rate shows a characteristic upward curvature that is caused by a combination of dead-time and Z- effects. The cubic fit has excellent correlation with the data. The fit is constrained to pass through the origin, assuming there is no background contribution to the probe response. A visually added straight line passes through the origin and the first calibration point, showing that the probe response to grade is linear for low grades, as expected. The second point, at 0.3827 % grade, deviates slightly from linearity, and the remaining higher grade points show more deviation from linearity as dead-time and Z-effect become more significant. The cubic fit was done using the trend line feature of Microsoft Excel. The third order polynominal option is selected using the Excel “trend line” feature. The option to constrain the fit to pass through the origin is also checked. This equation is used to convert log data counts/sec to in-situ uranium grade. The prefix “e” to grade signifies the fact that this is an equivalent grade with the assumption that radioactive equilibrium exists between the gamma emitting daughters and the uranium parent.

model ID	cts/sec	In-situ eU_3O_8 %
U1	131434	2.3536
U2	82041	1.0504
U3	38274	0.3827
N3	21474	0.2010

This simplified method has not yet been applied to the calibration sites at Casper, Grants, and George West. It is expected, however, that results will be similar with the use of four models to define the polynomial fit.



If the field logging is done in water-filled boreholes, then the logged grade must be multiplied by a correction factor (greater than unity) based on the Grand Junction water factor measurements and the known diameter of the borehole. Similarly, if the borehole is cased, or logging is done through drill pipe, a casing correction will be required.

The resulting grade versus depth is an “apparent” grade that is not corrected for the smearing effect of probe response. For example, a 2-inch thick U zone with barren zones above and below, will result in a log curve of grade versus depth that is smeared to a full-width half-maximum of about 10 inches, with a maximum apparent grade considerably less than the actual thin zone grade. As discussed previously, however, the grade times thickness product obtained from this log will be correct, though the apparent distribution with depth is incorrect.

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