Hanford's Decision Level for Alpha Spectrometry Bioassay Analyses Based on the Sample Specific Total Propagated Uncertainty

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The bioassay program for the entire Hanford workforce is managed by the Pacific Northwest National Laboratory. Until April 2000, the decision levels by which samples containing elevated quantities of radioactive material were identified were all specified in the contract with the analytical laboratory as absolute activity values. The contract specified an upper bound for the minimum detectable activity (MDA) for each analysis (the contract limit), and established the decision level at one-half the contract limit (CL). For most alpha spectrometry analyses the CL was 0.02 dpm per sample. The decision level was applied to the activity result, rather than the count data. The detection criterion was therefore insensitive to sample specific variables such as chemical yield and detector efficiency.

In order to select a better procedure, an investigation of the ANSI N13.30 and other proposed decision level equations was initiated (Strom and MacLellan, 2000). The investigation concluded that the ANSI N13.30 equation significantly underestimates the number of false positive results. The maximum number of false-positive results peaks at about one background count during the counting period, but remains significant up to an expected 100 counts. The ANSI N13.30 equation answers the question "For a given background count rate, how large a net count will be observed less than "alpha" percent of the time, if there is no activity in the sample?" An equation proposed by Altshuler and Pasternack in 1963 (Eq.1) was found to be far superior:

$$\Delta_1 = k_a \sqrt{2n_b}\left(\frac{k_a}{\sqrt{8n_b}} + \sqrt{1+\frac{k_a^2}{8n_b}}\right) \qquad \text{Eq. 1}$$

where Δ_1 is the decision level, n_b is the background count, and k_α is the abscissa of the standardized normal distribution corresponding to the probability level 1 - α. That equation answers the question "How much activity can be in a sample, and the confidence interval for the net count still include zero?" The decision level obtained from the Altshuler and Pasternack equation remains unbiased down to an expected three counts during the counting period.

The concept of the Altshuler and Pasternack (1963) equation was adopted for the Hanford bioassay program, but an additional simplification was incorporated. The actual form of the equation used in our previous investigation calculates the decision level based only on the number of observed background counts. However, the original form of the equation used in the derivation equates the decision level with a multiple of the standard deviation estimate of a net count value (Δ_1). That is, the decision level is derived from the following equation:

$$\Delta_1 = k_a \sqrt{n_g + n_b} = k_a \sqrt{\Delta_1 + 2n_b} \qquad \text{Eq. 2}$$

where n_g is the gross count, n_b is the background count, and (n_g+n_b) is used as the estimate of the net count variance. Equation 1 is derived by solving Equation 2 for Δ_1. Hanford uses L_c to represent the decision level, rather than Δ_1.

The Hanford bioassay contract requires an estimate of the total propagated uncertainty (TPU) for each result reported, and the analytical laboratory uses the following equation for that calculation:

$$TPU = AC \sqrt{\left(\frac{\left[C_a + \left(C_{ba} \times \frac{t_a}{t_b} \right) \right]}{[C_a - C_{ba}]^2} \right) + \left(\frac{\left[C_t + \left(C_{bt} \times \frac{t_a}{t_b} \right) \right]}{[C_t - C_{bt}]^2} \right) + U_v^2 + U_t^2 + U_S^2} \qquad \text{Eq. 3}$$

where,

$$AC = \left(\frac{(C_a - C_{ba})}{(C_t - C_{bt})} \times A_t \right) \times \frac{1}{V_a}$$

A_t =Yield monitor activity
C_a = gross counts in the sample region of interest (ROI)
C_b = gross background counts in the sample or tracer ROI, as appropriate
C_{ba} = background gross counts in the sample ROI for the same counting time as the sample, $C_{ba} = C_b$ x (t_a/t_b).
C_{bt} = background gross counts in the yield monitor ROI for the same counting time as the sample, $C_{bt} = (t_a/t_b)$.
C_t = gross counts in the yield monitor ROI.
t_b = background counting time in minutes.
t_a = sample counting time in minutes.
V_a = sample size in the appropriate reporting units. e.g. grams, kg, etc.
U_s = systematic procedure error, typically 3% (0.03)
U_t = random tracer-activity error, typically 3% (0.03)
U_v = random volume-measurement error, estimated to be 1.5% (0.015).

It is therefore simple to implement a sample specific decision level based on the TPU. Rather than using equation 1 , Hanford alpha spectrometry decision levels are set from equation 2, substituting the TPU for the radical. A k_α value of 2 was chosen in order to maintain the average decision level near historic levels. The decision level then takes the following simple form:

$$L_C = 2(TPU) \qquad \text{Eq. 4}$$

This decision level has been used by many laboratories in its empirical form for many years. With this equation, about two percent of the results are expected to be false positives assuming a normal distribution of the net count. Table 1 is a summary of data produced by a Monte Carlo simulation program (Crystal Ball™™) when the alpha spectrometry process was modeled, and the Altshuler and Pasternack decision rule applied. The model assumes a 2500-minute count time, 70% chemical yield, and 32% detector efficiency. All count data are assumed to follow a Poisson distribution, chemical yield a normal distribution, and detector efficiency a triangular distribution. The count uncertainty is by far the most significant contributor to the total propagated uncertainty.

The Hanford decision level methodology is expected to provide an unbiased decision level at least down to 3 background counts, and will not result in excessive false positive results even for detectors with a background count of one.

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Table 1. Estimated Decision Level (DL) and Minimum Detectable Activity (MDA)

	Background True Mean,	Mean DL		False Positive	MDA (5% False Negative Probability)	
k_α	Counts	Net Counts	dpm	Probability	Net Counts	dpm
1.645	1	2.7	0.0049	2.6%	10.4	0.019
	2	3.7	0.0067	5.1%	12.0	0.021
	3	4.6	0.0082	4.8%	13.5	0.024
	4	5.3	0.0094	4.5%	14.9	0.027
2	1	3.3	0.0059	0.2%	12.5	0.022
	2	4.6	0.0081	1.1%	14.0	0.025
	3	5.5	0.0099	1.6%	16.2	0.028
	4	6.4	0.0115	2.0%	17.5	0.031

References:

Altshuler, Bernard and Bernard Paternack, Statistical Measures of the Lower Limit of Detection of a Radioactivity Counter. Health Physics 9:293-298; 1963.

Strom, Daniel J.and Jay A. MacLellan. Traditional Formulas For Decision Level Are Wrong For Small Numbers of Counts. Health Physics (in press).

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