Making Counting Decisions

Use/Misuse of Sample Statistics

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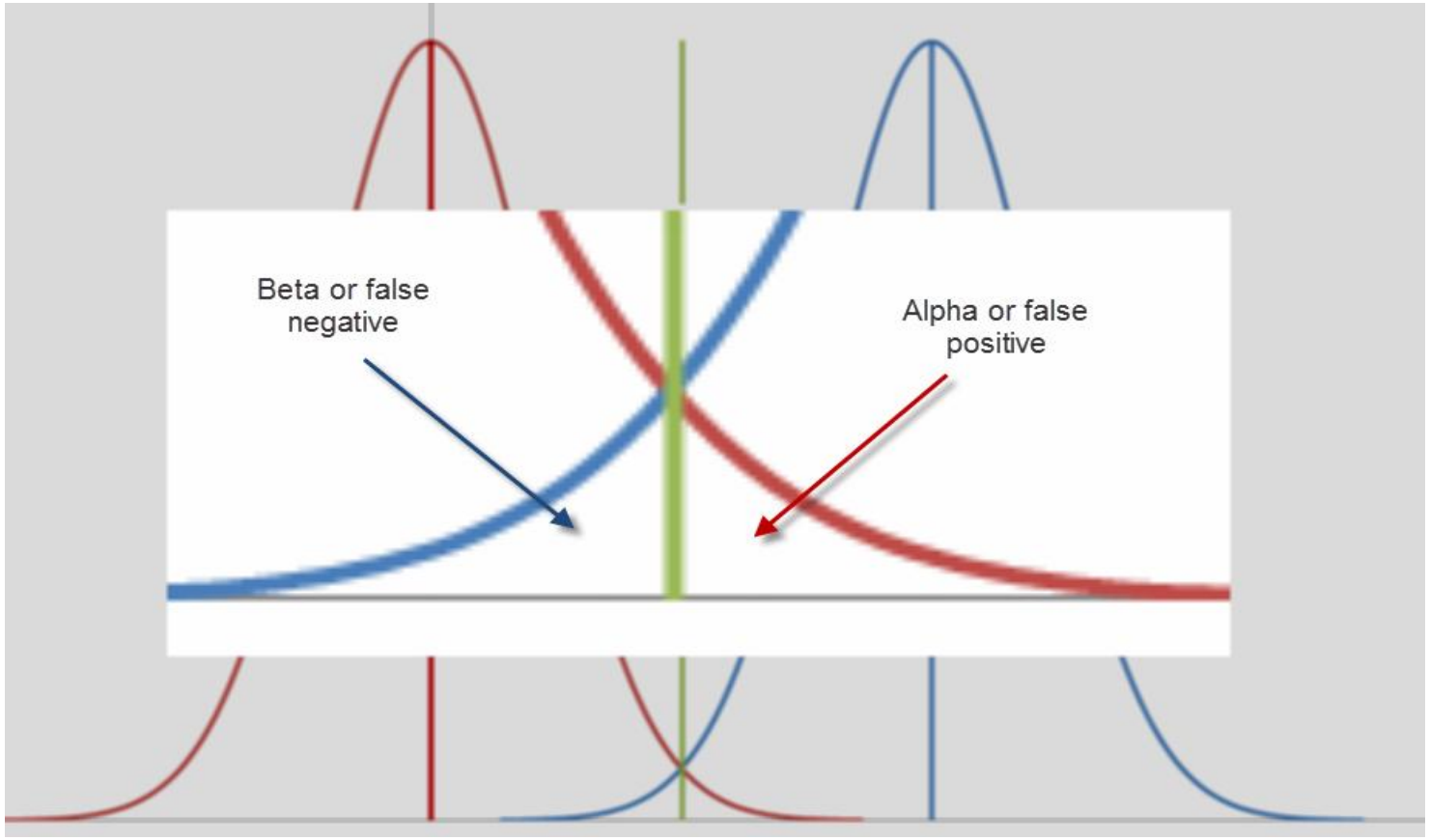
Issues

There seems to be a some confusion with the terms LLD, MDL (or MDC) and what is a positive result (Critical Level???).

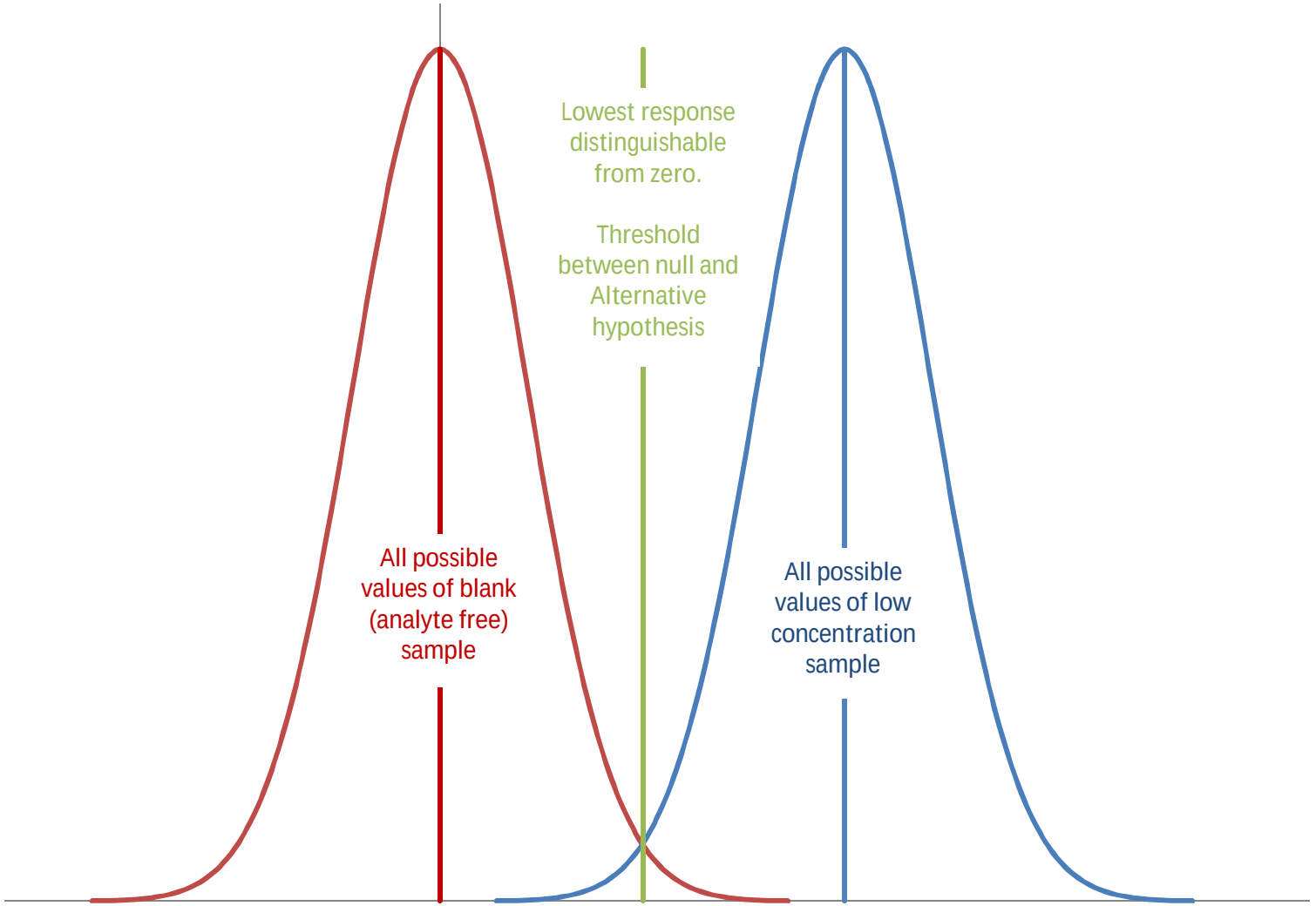
Need to address this confusion to clarify our fleet procedure on Groundwater monitoring.

α and β

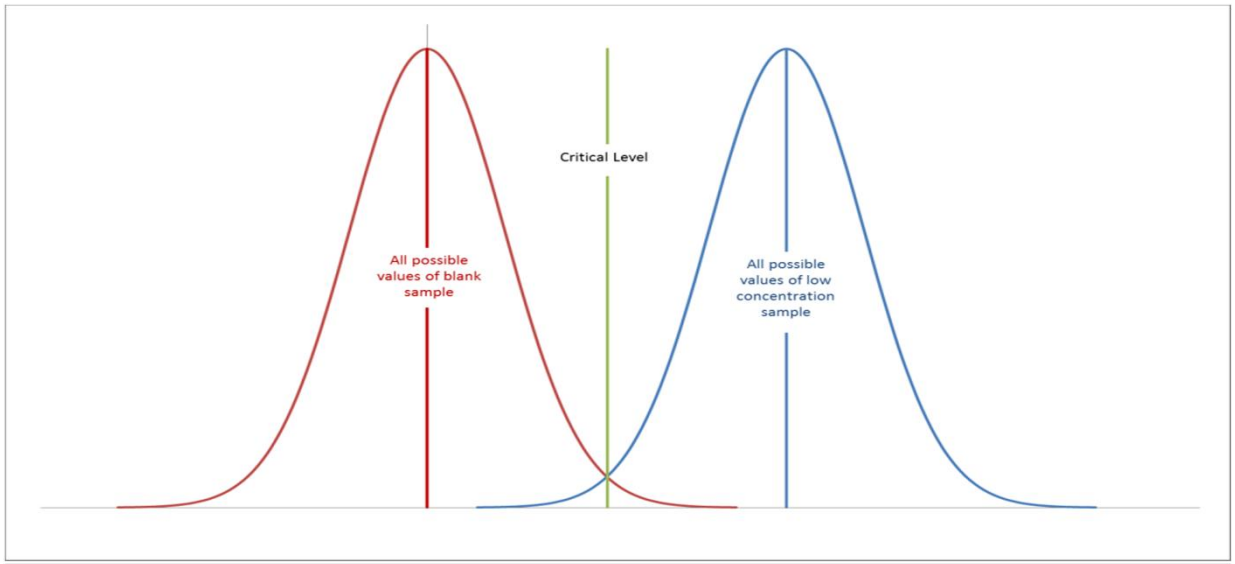


Confidence Level = [100% - (α + β)], therefore detection limit and confidence level are inextricably linked.

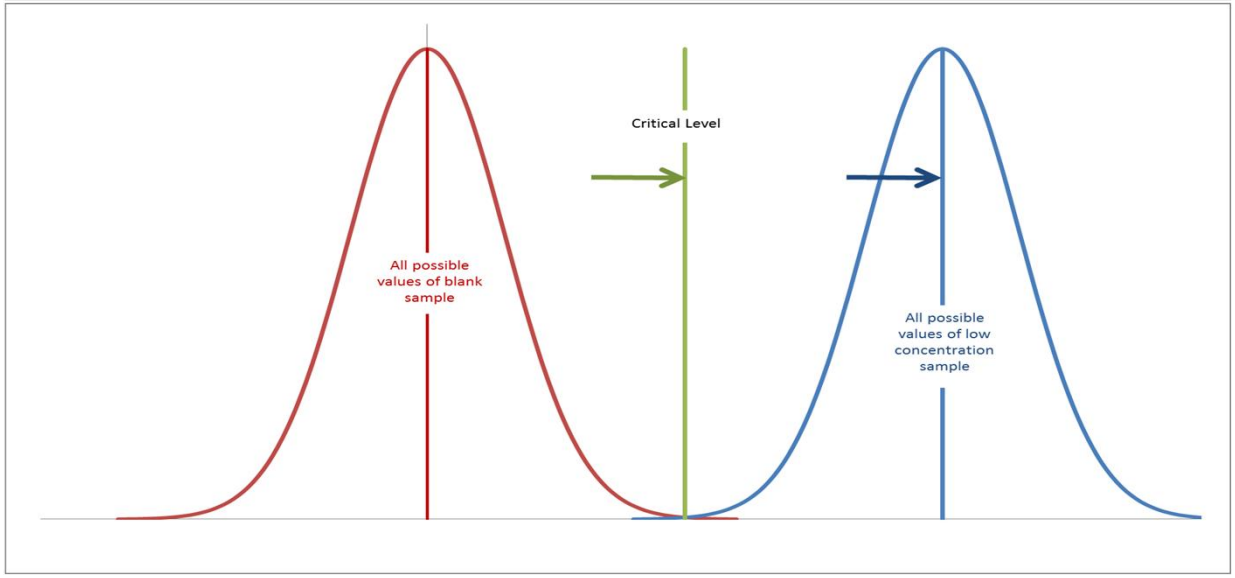
Blank and Low-Concentration Curves



Critical Level & MDC

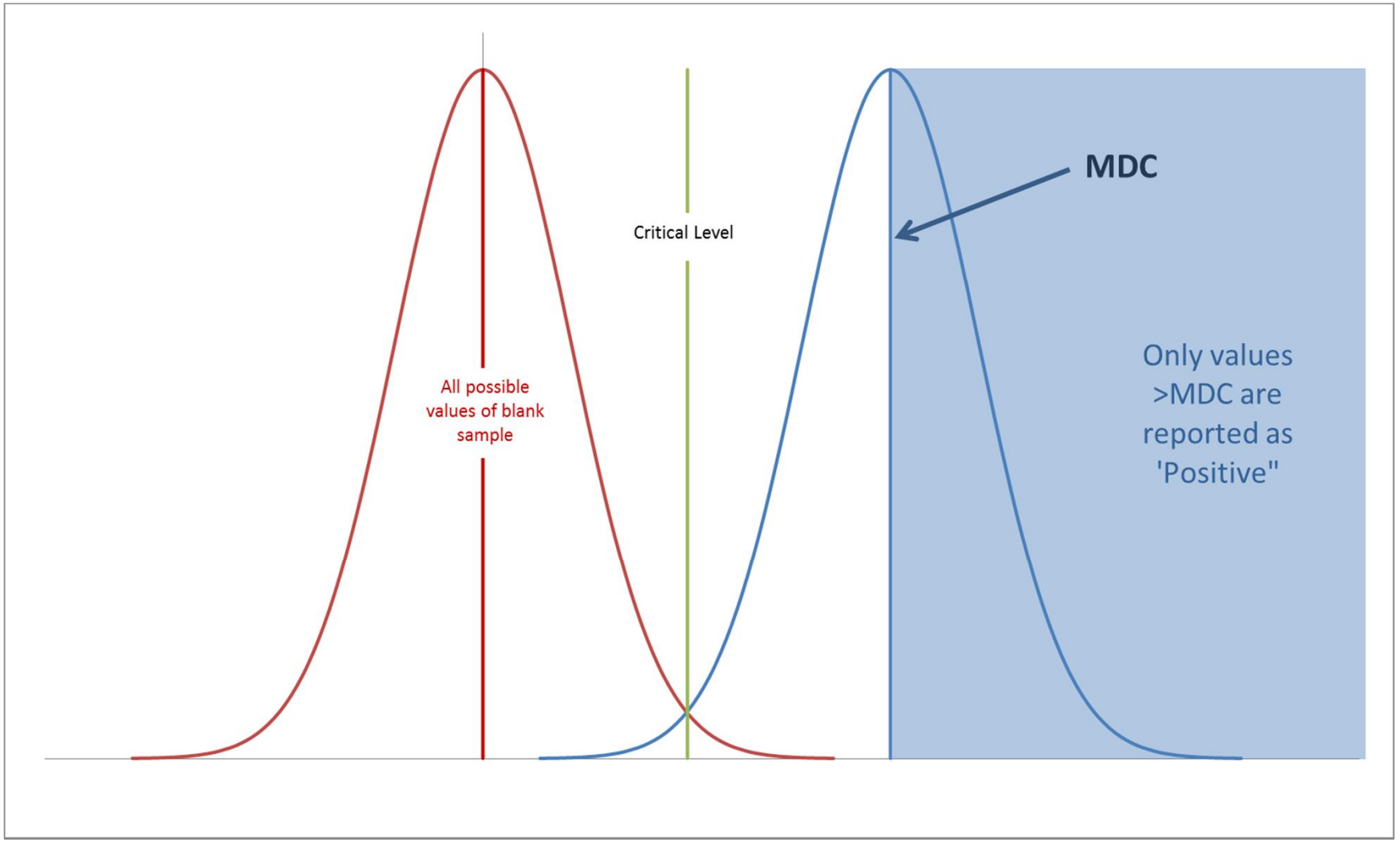


Decreasing the probability of a false positive (α) or false negative (β) Results in increasing The Critical Level and the MDC/LLD.

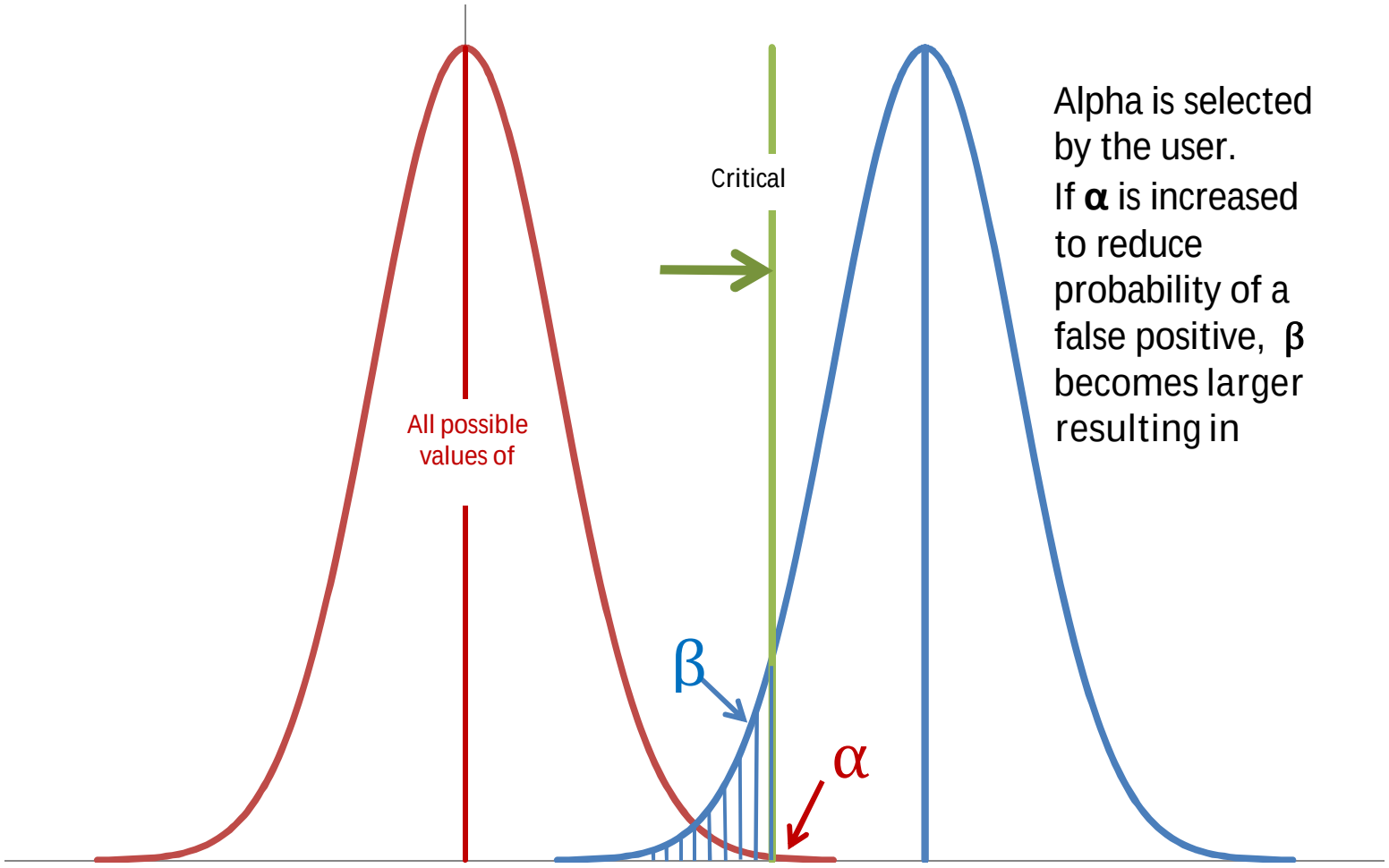


Therefore, ironically reducing risk of non-identification leads to less sensitive analysis.

Using MDC as Detection Limit



Reducing α



Alpha is selected by the user.

If **α** is increased to reduce probability of a false positive, **β** becomes larger resulting in

References

- EPA – Dr. Keith McCroan – National Analytical Radiation Environmental Laboratory (2013 webinar)
- Altshuler & Pasternack, Health Physics, 1963
- Dr. Daniel Strom, “False Alarms, True Alarms, and Statistics: Correct Usage of Decision Level and Minimum Detectable Amount”, Pacific Northwest Laboratory, Continuing Education Lecture, Health Physics Society, July 15, 1998.
- Allen Brodsky and Robert Gallaghar, “Statistical Considerations in Practical Contamination Monitoring”, Radiation Protection Management, July/August 1991
- Upgrading Environmental Radiation Data, Health Physics Society Committee Report - HPSR-1 (1980), EPA 520/1-80-012, U. S. EPA Office of Radiation Programs, August 1980
- MARLAP Volume III (18.6.1 Detection Capability and 20.2.6 Other Detection Terminologies) (NUREG 1576)
- 40CFRPart 136, Appendix B (Method Detection Limit)
- A. Brodsky, “Accuracy and Detection Limits for Bioassay Measurements in Radiation Protection”, NUREG 1156
- EPRI 1025311
- March 26, 2013 EPRI Webinar
- Currie, “Lower Limit of Detection: Definition and Elaboration of a Proposed Position for Radiological Effluent and Environmental Measurements”, NUREG/CR-4007 NUREG CR-4007

Altschluer & Pasternack

Health Physics 1963

Two measures [of the limit of detection] will be presented in this paper. One establishes a critical value of measured activity, which shall be called the "minimum significant measured activity," such that the true activity is judged to be zero or greater than zero according to whether the measured activity is less than or not less than this critical value.

Altschluer & Pasternack

continued

The second measure, to be called the "minimum detectable true activity," is the smallest value of the true activity such that a measured activity can be expected, with a given degree of confidence, to be greater or equal to the critical value—i.e. to imply correctly that true activity is greater than zero.

Current Practices

- Currently we call this "minimum detectable true activity" the LLD (per Curie and NUREG 1301/1302); we define it as before the fact (before counting the actual sample) – and typically it equates to some constant (2.71) plus 4.66 $\sigma_{background}$
- We also use MDL and usually it is after the fact – typically between 2 and 4.66 $\sigma_{background}$. MDL may be in counts while MDC may be in pCi/unit but they are virtually equivalent --- however some statisticians don't bother with the after the fact and just call LLD and MDL equivalent (i.e., don't bother with the after the fact assessment since they use Critical Level in determining a positive result)
- However: Most references agree that: using the minimum detectable value (MDL or LLD) instead of the critical value as a threshold for detection is a <u>mistake</u>

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Other Terminology

- The following terms may be used for the “critical value” in radiochemistry:
  - Critical value (IUPAC 1995)
  - Critical level (Currie 1968)
  - Decision level (ANSI N42.23)
  - Decision threshold (ISO 11929)
  - Decision limit (Currie 1968)

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Mistake #1

- Worst mistake: using the minimum detectable value instead of the critical value as a threshold for detection
- This mistake *may* be less common now than in the past, but it still happens
- Possible reasons:
  - Terminology hasn't been self-explanatory (e.g., "critical value" or "critical level" means little if you don't know statistics)
  - Mathematically precise, correct definitions, whose meanings are clear—to mathematicians
  - Failure to distinguish between true values and measured values
- Related mistake: censoring results < MDA
  - Any censoring interferes with statistical analysis of data
  - Censoring results < MDA is especially hard to justify, given that the MDA is not a detection threshold

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Mistake 1; Consequences

- If we specify that $\beta = 0.05$ at the MDA, then *if the true analyte activity equals the MDA*, there should be a 95% probability of detecting it
- If you use the MDA as your detection threshold, you'll actually call the analyte "detected" only about 50% of the time
  - Because half the time the observed value will be less than the MDA and half the time it will be greater
- This mistake degrades true detection capability
  - But it does greatly reduce false positive rates

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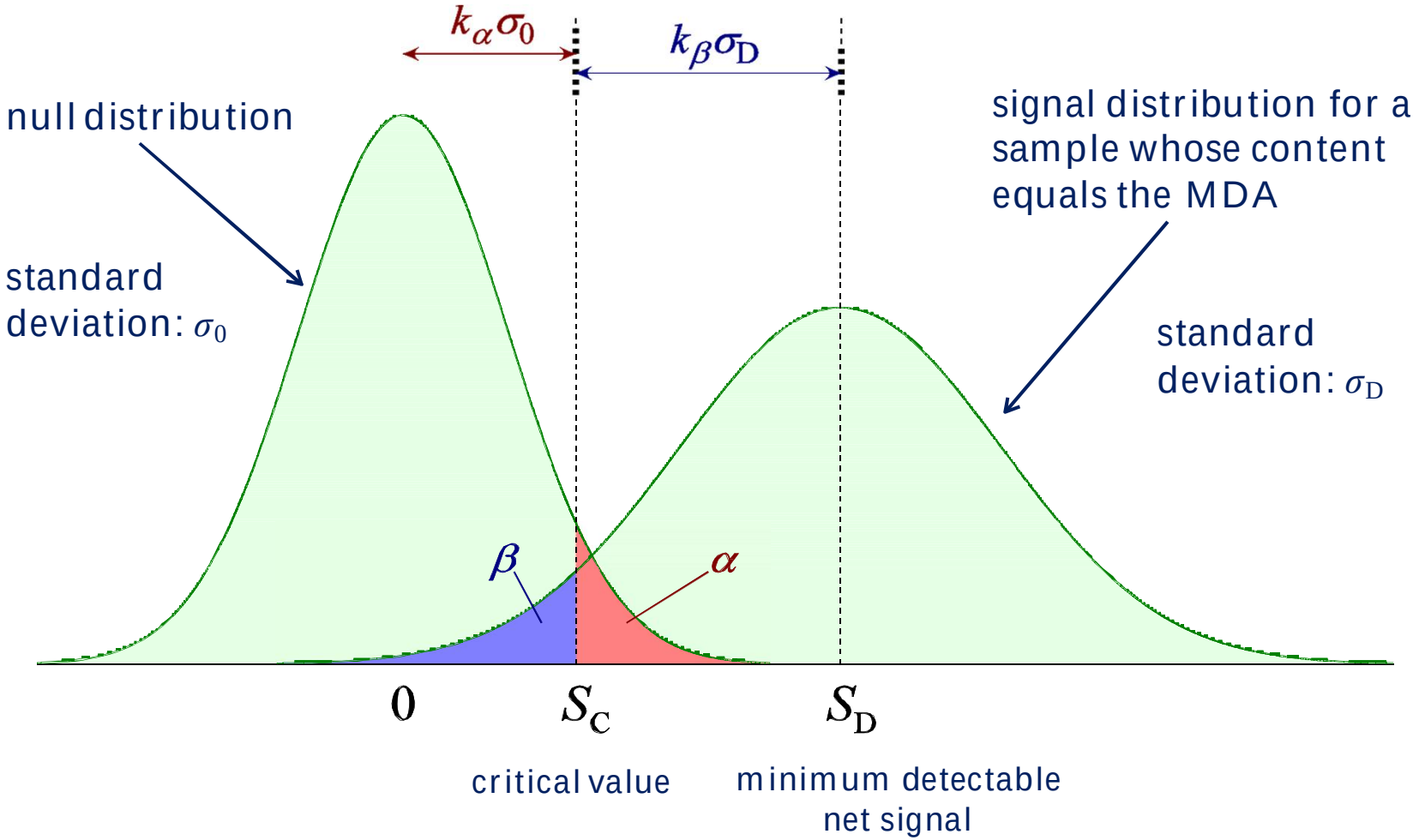
Critical Value and Minimum Detectable Net Signal



Critical Level

- Since background and sample are very close, assume equal
- $k_\alpha \sigma_o \sim k_\beta \sigma_D$
- If $k_\alpha \sigma_o + k_\beta \sigma_D = 4.66$ (per NUREG 1301/1302)
- $k_{0.05} = z_{0.95} = 1.645$
- $k_{0.01} = z_{0.99} = 2.326$
- Then CL = 4.66/2*2.326/1.645 σ = 3.29 σ

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Mistake #2

- Using popular equations for the critical value and MDA without understanding them or their limitations
  - There isn't just one correct equation that works in all cases, but for any situation there are many incorrect equations
- Examples
  - Taking the best available critical value for gross counting and trying to use it for gamma-ray spectrometry
  - Using an equation that incorrectly assumes equal count times for sample and background
  - Assuming pure Poisson statistics despite abundant evidence of non-Poisson effects, e.g., in backgrounds or method blanks
  - Neglecting interferences (e.g., ROI spillover in alpha-spec)
  - Using traditional Poisson-based equations at very low background levels

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Mistake #3

- Ignoring method blank results
  - Is uncorrected contamination in the measurement process making the blanks positive?
  - Then what are the critical value and MDA good for?
  - We assume sample results are corrected for known systematic effects, making mean blank activity ~0
  - If that isn't true, the critical value and MDA are misleading

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Mistake #4

- Many applications to γ-ray spectrometry
  - Except where the detection decision is based on one predetermined photopeak
- Detection algorithms for γ-spec are usually more complicated, making the true MDA harder to estimate
  - What effect does a Mariscotti peak search have on the detection rate?
  - If 2 or more good peaks are needed for detection, you can't base the MDA on just the most abundant or cleanest peak
    - Detection probability is limited most by the *worst* of the required peaks, not the *best*.

Dr. Strom

- Currie's "detection level" (a.k.a 'lower limit of detection", minimum detectable activity" is more appropriately called an "advertizing level"
- "Never compare a measurement result with and advertizing level (MDA); compare measurement results with a false alarm level (DL)(also called critical level)
- The MDA is really the "if it's in the sample you're likely to detect it while the DL is the "if you got a a result above this, it's probably real"

EPRI 1025311

Detection Capability (Sensitivity) – page 6-2

- "A sample containing a concentration equal to the MDC will be measured above the critical level, about 95% of the time. Numerically, the critical level is about 1.5 to 2 times the measurement uncertainty when measuring a blank , and the MDC is about twice the critical level or about 3 or 4 times the blank measurement uncertainty [MARLAP 2004]"
- "The practice of comparing a measured concentration to the MDC to male a decision is incorrect from a statistical basis, since MDC is defined based on a comparison to the critical level [MARLAP2004]. Further discussion on the definition and application of the critical level and MDC are given in MARLAP and Currie [Currie, 1968]"

Assessing Positive Results – page 7-4

- '' … the critical level (called critical value in MARLAP)is chosen so that when a blank (or analyte-free) sample is analyzed, there should be at most a 5 % probability of incorrectly deciding that the analyte is present."

EPRI 1025311

Assessing Positive Results (cont.) – page 7-4

- ‘’ … in practice some difficulties arise. A false positive rate of 5% becomes statistically significant for analyses such as gamma spectrometry where twenty or more radionuclide concentrations are often reported together. In this case, approximately one false positive result would be expected per analysis, which may not be confirmed by reanalysis.” Thus, some facilities use the MDC as a type of decision level or significance level, where is a radionuclide is detected above this level an action, such as reanalysis is initiated. Radioactivity present in a sample at a concentration greater than the MDC should be detected above the critical level with a frequency greater than 95%.

  The comparison of measured activity to the critical shold not be ignored, however. Assessing the frequency of detection for each radionuclide above the critical level can not provide earlier warning of the true presence of a radionuclide in groundwater, but also warn of method biases or sample contamination.”

EPRI 1011730

- “In order to concentrate efforts on analyses with the most significant bias, it may be useful to use a 3 σ criterion to identify, with a high degree of confidence (i.e., at the 99.97 % confidence level) analyses with significant bias with respect to the underlying background or baseline.

EPA

40CFR Part 136 Appendix B - Definition and Procedure for the Method of Detection Limit – Revision1.11

Definition - The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero and is determined from analysis of a sample in a give matrix containing the analyte.

Allen Brodsky and Robert Gallaghar

- The intention is that detection capability should not be claimed at levels below the MDA. On the other hand, as shown in section 2, results should be reported below MDA, together with standard errors (or other defined confidence intervals). If “less than” results are reported at all, they should be indicated as less than the associated decision amount, DA.

HPSR-1 (1980), EPA 520/1-80-012

- "The frequent use of an MDC of LLD as a criterion for excluding some results from the data reports must not continue. The resulting positive biasing effects of this practice were discussed previously. As a resullt it is recommended that all measurement reports be reported directly as found; and that 'less than MDC" and similar terms not be used."
- Measurement of a hundred different radionuclides in a surveillance or monitoring program is neither reasonable or justifiable…The criteria should be measure (and hence reported) should be based upon what is actually needed for the of the environmental radioactivity monitoring and upon the dose significance of the radionuclides." (NUREG-0475 listed a reference for this statement)

Test Data

2 sigma			a true null data set should be 95%					$>2\sigma$	>MDA	difference
	Cs-137									
		total data	239		observed%	95.3%		18	7	11
		"true pos"	7							
		null data	232							
	Sr-90									
		total data	239		observed%	87.0%		79	55	24
		"true pos"	55							
		null data	184							
3 sigma			a true null data set should be 99+%					$>3\sigma$		
	Cs-137									
		total data	239		observed%	99.6%		8	7	1
		"true pos"	7							
		null data	232							
	Sr-90									
		total data	239		observed%	100.0%		55	55	0
		"true pos"	55							
		null data	184							

Summary

- Still use LLD as “a priori” and compare “a posteriori” to this per NUREG 1301/1302
- Determine critical level – may need to be 2.33 σ for “gross counting” (H-3, Sr-90, Fe-55, Ni-33, …) and 3.29 σ for gamma spectroscopy
- All data (at least from the lab) needs to be reported

Questions/Comment