A Methodology to Address Varying Background in Scanning Surveys

Jan Irvahn, Jen Huckett, Dan Fortin, Lisa Newburn, and Debbie Fagan

Minimum Detectable Concentration

The U.S. Nuclear Regulatory Commission (NRC) requires facilities to demonstrate that residual radioactivity meets release criteria when decommissioning licensed sites. The decommissioning process typically includes radiation surveys, scans for radioactivity, to demonstrate compliance with NRC dose limits. The design of these surveys often includes the calculation of a minimum detectable concentration, a Scan MDC. The Scan MDC (units vary) establishes a lower bound on the amount of radioactivity a planned survey can reasonably expect to detect. If this lower bound is higher than what is needed to demonstrate compliance the surveyor can consider different detectors, different detector configurations, or different survey designs.

Net Counts

The current statistical framework used to calculate MDC is based on counts and was published in Currie 1968. There have been many documents containing guidance published since including NUREG-1507, NUREG/CR-6364, and Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM). The core physics model that MDC calculations are built on is a Poisson distribution of counts of radioactive decay events. The core statistics model is a hypothesis test for the mean of a distribution being greater than 0.

$B \sim \text{Poisson}(\lambda_B)$	background counts
$X \sim \text{Poisson}(\lambda_X)$	observed counts
$X \dot\sim \text{Normal}(\mu = \lambda_X, \sigma^2 = \lambda_X)$	normal approx to Poisson
$D = X - \frac{1}{N}\sum B$	Test Statistic
$E[D] = 0,\ \lambda_X = \lambda_B$	H_0
$\text{Var}(D) = \text{Var}(X) + \frac{1}{N}\text{Var}(B)$	
$= \left(1 + \frac{1}{N}\right)\lambda_B$	under H_0
$L_C = k_\alpha \sqrt{\left(1 + \frac{1}{N}\right)\lambda_B}$	critical level

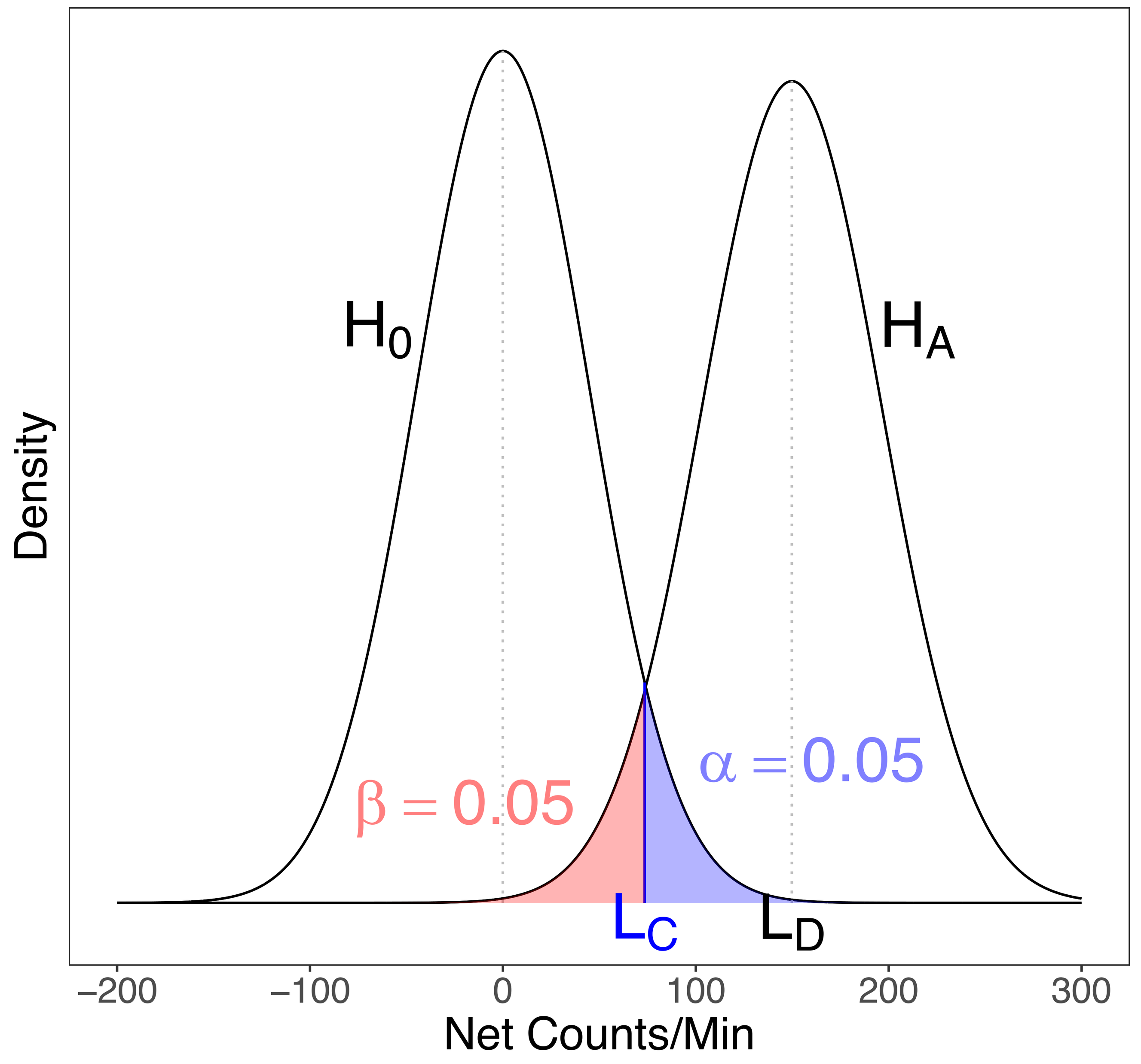
Typical regulations are primarily concerned with activity *above* a background level of activity, so the statistical framework includes the subtraction of a background signal when establishing the MDC. The notation adopted here assumes each observation, each count, is based on the same amount of scanning time, say 1 second. An observation from the region of interest can be directly compared to an observation from a reference area that is used to establish the background level.

Uncertain Background

Background levels are never known exactly, so variation in the test statistic comes both from the measurement at the location of interest and from the measurement(s) used to establish the background. Uncertainty in the average background count rate can be decreased by counting for longer times, or equivalently, by taking many measurements from the reference area assumed to be representative of the proper background.

Trouble arises when the potentially contaminated area of interest has different background levels in different locations. Using an overall average background level can, potentially, lead to two types of problems. First, contaminated locations in areas of low background activity can go undetected because the sum of background counts and source counts may not exceed the critical level threshold. Second, uncontaminated locations in areas of high background can exceed the critical level threshold far too often, triggering too many unnecessary follow up activities.

Test Statistic, Normal Approximation



Local Hotspots, Local Background

We proposed a method that can accommodate non-constant background in situations that satisfy two constraints related to the length scale of the potential contamination. First, the contamination of concern needs to be localized so that hot spots do not extend beyond that length scale. Second, while the background does vary across the survey site, the background varies minimally over distances of that length scale.

When both criteria are met, we proposed estimating background, not from a separate reference site, but from select measurements taken in the same survey, measurements that are close but not too close to the location of interest. The select measurements need to be close so that the background estimate is appropriate. The select measurements can't be too close because we need to prevent potential source counts from being included in the background calculation.

When surveying a linear transect, a 1-dimensional, constant speed with regular measurements, every measurement is the same distance from its immediate neighbors. A relatively simple version of our lag-k method uses two measurements to estimate the background for each hypothesis test, one measurement a 'distance' k measurements ahead of the location of interest and one measurement a 'distance' k measurements behind. Future work can explore more sophisticated approaches for establishing the appropriate criteria for 'close, but not too close' and sensible weighting schemes to accommodate variability in background across a survey region of interest.

$E[D] = L_D,\ \lambda_X = \lambda_B + L_D$	H_A
$= \left(1 + \frac{1}{N}\right)\lambda_B + L_D$	
$L_D = L_C + k_\beta \sqrt{\left(1 + \frac{1}{N}\right)\lambda_B + L_D}$	solve for L_D
$L_D = 2L_C + k_\alpha^2$	when $\alpha = \beta$

References

Currie, L. A. 1968. "Limits for qualitative detection and quantitative determination. Application to radiochemistry." *Analytical Chemistry* 40 (3): 586–593.

NRC (U.S. Nuclear Regulatory Commission). 1998. *Human Performance in Radiological Survey Scanning*. NUREG/CR-6364, BNL-NUREG-52474, Washington, D.C.

NRC (U.S. Nuclear Regulatory Commission). 2020. *Minimum Detectable Concentrations With Typical Radiation Survey Instruments for Various Contaminants and Field Conditions*. NUREG-1507, Washington, D.C.

NRC/EPA/DOE (U.S. Nuclear Regulatory Commission, U.S. Environmental Protection Agency, U.S. Department of Energy). 2000. *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)*. NUREG-1575, Rev. 1, EPA 402-R-97-016, Rev. 1, DOE/EH-0624, Rev. 1, Washington, D.C.

U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

For additional information, contact:

Jan Irvahn | (509) 371-7393 | jan.irvahn@pnnl.gov

10/10/23 | PNNL-34211

Pacific Northwest NATIONAL LABORATORY

www.pnnl.gov