RADIATION PHYSICS NOTE 108

Survey Instrument Based Release Criteria and DOE Policy

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May 1993

Introduction

This radiation physics note was undertaken to propose a practicably implementable method for interpretating the current DOE policy of "no radioactivity added as a result of DOE operations" (colloquially known as the "no rad added" policy).

Over the last two and one half years (10/90 through 4/93) the national contractor laboratories have attempted to find some common ground with DOE for interpreting the "no rad added" policy. As a result of these efforts, the interpretation of "no rad added" has evolved from "contains no measurable increase in radioactivity (at a statistically defined confidence interval) above background" to an L_c[1] value at a 95% confidence level. How one defines "no rad added" has been and remains the central issue in the DOE imposed waste moratorium.

The traditional method of defining "no rad added" is that any material exhibiting a count rate on an appropriately chosen instrument equal to or exceeding twice the measured background count rate was considered radioactive by definition; an appropriately chosen instrument meaning that an instrument which maximizes the detection potential for the radionuclides most likely to be in a given material is chosen. When all known major sources of random error are considered, this method is consistent with the detection limits of the instrument, with all currently published information for protecting the public and the environment, and with the "no rad added" policy. It is this method which is endorsed by this note.

Theory

In any measurement there are two general classes of error,[2] random and systematic. No measurement can be fully evaluated with respect to its precision, accuracy or information conveyed; until the individual sources of error which contribute to each of these error classes are fully understood and accounted for. Virtually any measurement will contain errors of which the investigator is unaware due to this finite knowledge of the measurement process. However this fact does not imply an abandonment of effort since one can usually estimate the dominant errors in most routine measurements. Scientists and engineers rely on understanding the dominant errors in any measurement process before they quote the results or arrive at any concomitant conclusions.

The term error implies the existence of a "true" value for the parameter being measured. Thus when one makes a measurement or a series of measurements of some parameter and assigns an error to that result, he is making a probability statement concerning the relationship of that result to the "true" value of the parameter. This process becomes particularly tenuous when attempts are made to measure parameters close to the detection limits of the instruments used in making the measurements. No measurement can be adequately evaluated independent of all the major errors inherent to it or of the context in which it will be applied.

The Problem

The specific parameter which we want to consider measuring in this particular note is the amount of volume or bulk radioactivity different from normal background contained in a material sample. Superficially this statement sounds straightforward; however there are several practical measurement questions tied up in it. First, what instrument or instruments will be used for the measurements? How many measurements of background are necessary to establish an accurate background mean count rate? How many measurements of the material sample are necessary to establish an accurate mean for the sample count rate? What sources of instrument error exist other than statistical ones? And most important, what does the measurement really tell you about the potential radioactivity in the material?

From a legalistic point of view the "no rad added" must be interpreted to mean that not one atom of radioactive material has been added by DOE operations. Obviously this is an untenable position, since the technology to make such a determination does not exist. Everything in the known universe contains radioactivity and the only relevant question is, how sophisticated a measurement is necessary to quantify it. Therefore the interpretation of "no rad added" must be subjective. There is no *a priori* reason for preferring one interpretation over another.

For national laboratories, such as Fermi National Accelerator Laboratory (FNAL), which have many small diverse waste streams it is impractical and cost prohibitive to perform sampling and analysis on each waste stream. By analysis, I mean measurements performed with analytical instruments in a well-controlled laboratory environment. The only two other options for screening material and equipment are through generator knowledge or through measurements performed using field survey instruments. Generator knowledge can be used in a subset of cases but not all. Hence a method for screening materials and equipment using field survey instruments is essential.

Survey Instrument Measurements

The formulas expressed by Lochamy(1) presuppose that sufficient measurements have been performed to establish a valid mean background and standard deviation. It is also tacitly assumed that the standard deviation of any measurement is solely due to the statistics of the corresponding count rate. These assumptions are rarely valid in any practical situation and certainly not for field measurements. Dealing with realistic errors can result in vastly different estimates of critical levels and detection limits. For example, consider a field measurement performed on a 55 gallon drum using a Bicron Analyst™ survey instrument on the fast response setting in the meter readout mode.[1] Suppose further that a single reading of the meter yields a background of 2000 cpm.[2] Including the statistical error (σ_{st}), there are several other obvious sources of error in this measurement. Readout of the meter by the surveyor (σ_{ro}) is one. Another is the random background variation (σ_{bv}). If these are the only dominant contributors to the standard deviation of the background measurement (σ_B) and they are not correlated parameters, then σ_B is given by:

[1] It should be noted that Fermilab typically uses this particular field instrument arrangement because the NaI(Tl) detector is particularly efficient for detecting the presence of accelerator produced radionuclides. The instruments are used in fast response to minimize the potential of a surveyor missing hot spots due to variations in scanning speeds.

[2] Multiple determinations of the background would follow the standard rules for determining the arithmetic mean and standard deviation of the background distribution. For example see reference (3).

$$\sigma_B = \sqrt{\sigma^2_{st} + \sigma^2_{ro} + \sigma^2_{bv}} \tag{E.1}$$

where σ_{ro} can be estimated as ± 200 cpm, σ_{bv} can also be estimated[3] as ± 200 cpm and σ^2_{st} is the statistical error in determining L_c(1), i.e., $2\frac{R_b}{T}$ where R_b is the background count rate and T is the effective count time for the background. In fast response on the X10 scale the Bicron Analyst™ has a 1 second[4] response time.(3) Substituting, one obtains

$$\sigma_B \approx 566 \text{ cpm} \tag{E.2}$$

An equivalent critical value (L_c'), choosing k = 1.65, would then be

$$L_c' \approx 933 \text{ cpm} \tag{E.3}$$

L_c' is used to distinguish it from the L_c of Lochamy which only includes σ_{st} and is approximately 572 cpm. We can now continue and estimate a limit of detection (L_d') analogous to Lochamy's L_d. However this count rate (L_d') will now be a somewhat more complicated function of the background count rate(R_b). Suppose a sample count of 3000 cpm (R_s) is observed by the surveyor. The standard deviation (σ_s) for this measurement is given approximately by:

$$\sigma_s = \sqrt{\sigma^2_{ro} + \sigma^2_{sd} + \sigma^2_{ss} + \sigma^2_{d}} \tag{E.4}$$

where σ_{ro} is as previously defined, σ_{sd} is the error resulting from the variability of the distance between the detector and sample which can be quantified[5] as approximately ± 400 cpm and σ_{ss} is the error resulting from variability of the survey speed which can be quantified[6] as approximately ± 200 cpm. The statistical error (σ_d) in determining L_d is a complicated function of the background count rate and must be independently derived from Lochamy's formulas.(1) Statistical errors in the total observed count rate (σ_t) and the background count rate (σ_b) must be added in quadrature to evaluate the statistical error in $L_d(\sigma_d)$,

$$\sigma^2_d = \sigma^2_t + \sigma^2_b \tag{E.5}$$

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[3]Random background variations occur due to weather changes, differen t locations, and times during the course of a series of measurements. These random variations are distinct from purely statistical errors. Fermilab radiation technicians have observed background variations in excess of 200 cpm as recorded on a Bicron Analyst operated in the scaler count mode at different locations in the same building.

[4]Reference 6 actually quotes 1 second as the time required to reach 90% of the full meter response. One second is **not** the circuit time constant!

[5]This is a difficult error to estimate. In general the actual distance of a Bicron Analyst detector from the object during a contact survey can vary from 3mm to 15 mm. This will of course introduce a significant geometry error in detecting volume or bulk activation. In consultation with Fermilab radiation technicians and based on personal experience, this error has been approximated as 20% of the measured background.

[6]After consultation with Fermilab radiation technicians, this error was conservatively estimated at 200 cpm.

For a Poisson distribution, σ_t and σ_b can be expressed in terms of their respective count rates R_t and R_b:

$$\sigma^2_t = \frac{R_t}{T} \quad \text{and} \quad \sigma^2_b = \frac{R_b}{T} \tag{E.6}$$

Using the fact that the total count rate is the sum of the background count rate and the sample count rate (R_d) corresponding to the detection limit and substituting E.6 into E.5:

$$\sigma^2_d = \frac{R_d}{T} + 2 \cdot \frac{R_b}{T} \tag{E.7}$$

By definition:

$$R_d \equiv L_d \equiv L_c + k \cdot \sigma_d \tag{E.8}$$

where we will choose $k = 1.65$, which corresponds to a 95% confidence level. Substituting E.8 into E.7 and rearranging terms leaves a quadratic equation for σ_d.

$$\sigma^2_d - \frac{k}{T} \cdot \sigma_d - \left(\frac{L_c}{T} + 2 \cdot \frac{R_b}{T}\right) = 0 \tag{E.9}$$

Using Lochamy's definition of L_c and solving this equation for σ_d yields:

$$\sigma_d = \frac{k}{2T} \pm \frac{1}{2} \cdot \sqrt{\frac{k^2}{T^2} + 4 \cdot \left[\frac{k}{T} \cdot \sqrt{2 \cdot \frac{R_b}{T}} + 2 \cdot \frac{R_b}{T}\right]} \tag{E.10}$$

Substituting the appropriate numerical values, one obtains:

$$\sigma_d \approx 589 \text{ cpm} \tag{E.11}$$

as the statistical error for determining L_d. Going back to equation E.4 and substituting appropriate values for the various errors, one obtains

$$\sigma_s \approx 766 \text{ cpm} \tag{E.12}$$

An equivalent detection limit (L'_d) would then be given by:

$$L'_d = L'_c + k \cdot \sigma_s \tag{E.13}$$

Substitution of the appropriate numbers yields:

$$L'_d = 2196 \text{ cpm} \tag{E.14}$$

The analogous detection limit calculated using Lochamy's formula would be 1225 cpm. Clearly the inclusion of more realistic errors will increase the values of both L_c and L_d. In this simple example only the more obvious random error sources have been quantified and no effort has been made to estimate more esoteric systematic errors. The difference between L_d and the 2X background criteria is simply not significant.

Release Criteria

A release criteria based on the traditional 2X background level is practical, cost effective, simple to implement, consistent with the detection limits of survey instruments, and consistent with the stated guidance from DOE/EM-30,[7] i.e., no radioactivity present at levels statistically different from background at a 99.998% confidence level.

There is a release criteria which some (4),(5),& (6) wish to see implemented within DOE that is based on L_c as determined by a survey instrument equipped with an added scaler counter. This release criteria and measurement method are unacceptable for the following specific reasons:

(i) Use of L_c allows no margin for error due to statistical background fluctuations. A single background measurement could be located anywhere in the normal distribution. In order to implement L_c as a valid release criteria or decision level, the mean value of the background and its associated standard deviation must be established through multiple measurements of the background. Due to the known variations of background with time and location this procedure would have to be repeated frequently.

(ii) It would be impractical to use survey instruments in only the scaler counter mode. Such use would dramatically increase the time required to survey large items and increase the probability of hot spots being missed. At best, the scaler mode readout would have to be used in some prescribed combination with the meter mode readout.

(iii) The use of this criteria and method would be inconsistent with the cost effective implementation of worker and public radiation protection. For further details see reference (7).

(iv) Use of a scaler is inconsistent with ALARA since it requires the surveyor to spend more time around potentially radioactive material.

(v) Perhaps the most onerous consequence of this proposed procedure is the simple fact that when analytical laboratory measurements of an item lie between L_c and L_d, there is no reliable method to report specific radionuclide activities as required by DOE Order 5820.2A, especially if the instrument used in screening is the same instrument used to quantify specific radionuclide activities. Use of L_c would require the spectroscopist to report specific activities at only a 50% confidence level. Any reasonable release criteria must be consistent for both analytical laboratory and survey instrumentation.

(vi) The use of a release criteria based on L_c is inconsistent with waste minimization because such use guarantees that 5 out of every 100 samples surveyed will be declared radioactive whether they actually contain added radioactivity or not. It also guarantees that there will be a 50% chance that a repeat measurement of an item, containing radioactivity at a mean value of L_c, will fall below L_c.

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[7] DOE/EM-30 is the Department of Energy's Office of Waste Management.

Conclusion

Isolated statistical arguments should not be used as compelling evidence to support any particular point of view concerning measurement evaluation. The evaluation of how effective any measurement is must account for the instrument used, the confidence level adopted, the number of measurements used to establish mean values, and all of the important sources of error. There is no compelling reason to implement a release criteria based on L_c at a 95% confidence level as determined by survey instruments outfitted with a scaler counter. One might just as well decide to declare anything which exhibits even 1 cpm above the background mean value as radioactive. Of course such a policy would have many negative ramifications: one being that it would soon fill all our nation's repositories with radioactive waste; half of which would not be different from normal background. Regardless of what criteria DOE finally adopts, it will represent a *de minimis* value by default.

The time honored method of twice background is in fact a reasonable release criteria which is fully consistent with instrument detection limits and with the current DOE guidance. In the absence of acceptable consensus risk based *de minimis* values, use of this criteria with appropriately chosen instrumentation is the only reasonable course of action.

REFERENCES

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