SAMPLING PLAN DESIGN AND ANALYSIS FOR A LOW LEVEL RADIOACTIVE WASTE DISPOSAL PROGRAM

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ABSTRACT

Low level wastes that are candidates for BRC disposal must be subjected to an extensive monitoring program to insure the wastes meet (potential) bulk property and contamination concentration BRC criteria for disposal. This paper addresses the statistical implications of using various methods to verify BRC criteria. While surface and volumetric monitoring each have their advantages and disadvantages, a dual, sequential monitoring process is the preferred choice from a statistical reliability perspective. With dual monitoring, measurements on the contamination are verifiable, and sufficient to allow for a complete characterization of the wastes. As these characterizations become more reliable and stable, something less than 100% sampling may be possible for release of wastes for BRC disposal. This paper provides a survey of the issues involved in the selection of a monitoring and sampling program for the disposal of BRC wastes.

INTRODUCTION

Recently, there has been substantial interest and activity in the nuclear industry toward establishing a Below Regulatory Concern (BRC) contamination level for low level waste (LLW). Several methods can be employed to verify that waste streams are BRC. The purpose of this paper is to address the statistical implications of using various methods to verify potential BRC limits (1). The paper will discuss the types of monitoring equipment, the use of the equipment in a monitoring plan, the informational requirements and advantages of various monitoring plans, and the variables to be considered in the development of a statistically valid sampling plan based on a selected monitoring plan.

While the emphasis is primarily on Dry Active Wastes (DAW), this analysis applies to other waste streams with some modifications.

MONITORING EQUIPMENT

Monitoring equipment can be divided into two categories: surface and volumetric. Surface monitoring equipment consists of hand probes and other beta monitoring devices including conveyors and sorting tables which use gas flow proportional detectors. There are also some types of gamma devices which perform pseudo surface monitoring. These types of devices include tables and conveyors which use scintillation detectors. Volumetric monitors, on the other hand, primarily measure gamma radiation. These types of monitors have lead-encased detectors to exclude background radiation. Bag monitors have a lead-encased vault into which bags of DAW are placed. Another type of volumetric monitor *rotates* a barrel of waste with the lead-encased detector traversing the barrel from top to bottom. GeLi systems and NaI detector systems are also used for volumetric monitoring.

Surface monitoring will detect contamination located at or near the surface of waste but cannot detect contamination located within the waste itself. Surface monitoring is successful, however, in isolating highly contaminated areas (hot spots) which cannot be spatially located with a volumetric monitor.

Volumetric monitoring will detect both surface contamination and embedded contamination (if the contamination isotopes are gamma emitters). The bulk radiation dose properties of waste can be determined using volumetric monitoring, however, discrete identification (both location and activity) of contaminated areas of the waste is not possible with volumetric monitoring alone. Volumetric monitors can also identify the isotopic content of the waste if appropriate detectors are installed in the monitors.

Most volumetric monitors have excellent repeatability because of their shielding. Surface monitors tend to be less repeatable because they primarily measure beta radiation. Beta radiation has a limited range which is dependent on the energy of the particle. The ability to detect beta is also strongly dependent on the orientation and placement of the surface detectors with respect to the contamination.

Surface monitors are less susceptible to ambient radiation background fluctuations than volumetric monitors, This can lead to enhanced detectability in high background areas. Increased shielding is the primary method for reducing the effect of background on volumetric monitors.

MONITORING PLANS

A BRC monitoring plan can be developed using surface monitoring alone, volumetric monitoring alone, or a combination of surface and volumetric monitoring. The combined plan will provide greater assurance of meeting BRC limits.

A 1987 study at Carolina Power and Light (2) comparing monitoring equipment has shown that hand frisking DAW produces substantial errors when compared to a sorting table. Both hand frisking and sorting with a table result in bagged wastes which were rejected by a bag monitor. The implications of this study are discussed below.

The simplest monitoring plan entails the use of a hand frisking technique which is a familiar activity in all nuclear plants, Hand frisking is routinely used to survey both personnel and objects leaving potentially contaminated areas. The variability inherent in such a program, i.e. height of probe above object, rate of speed of survey, instrument meter readability (needle bounce), etc., does not allow for a valid statistical analysis.

The use of a single automated surface monitoring system, such as a table or conveyor, would improve the probability of detection of items near a BRC limit by eliminating the variability associated with hand frisking. Because of this, the percentage of misclassified waste would be greatly reduced. To reduce the probability of exceeding BRC limits may require that the instrument be set to a very low sensitivity to give an acceptable tolerance to preclude exceeding bulk limits for disposal. (Since BRC limits have not been established at the time of this publication, all references to limits are hypothetical.) For example, if all DAW in a given bag is close to the surface monitoring rejection point, the entire bag may exceed release criteria based on volume or weight while individual pieces passed surface release criteria.

The use of a volumetric system alone, on the other hand, will not identify the degree of concentration of activity within the waste. It should be noted that for some waste streams (liquid, soils, resins, etc.) volumetric measuring may be the only alternative for monitoring. For these streams, small sample/test volumes should be used to adequately identify hot spots if a non-homogeneous contamination is assumed.

Using a volumetric monitor without a surface monitor will confirm that bulk release limits are not exceeded. Without surface monitoring, there is a probability that the entire activity is concentrated on a single particle. If this probability is acceptable, volumetric monitoring can be used as the sole instrument for determining the total waste activity and disposing of the waste as BRC.

Use of a combined surface/volumetric monitoring minimizes the chance of concentrated activity and the chance that bulk limits will be exceeded. Combined monitoring can also reduce the probability of measurement error because the two methods overlap in the detection of many of the dominant isotopes found in waste streams, Cesium-137 and Cobalt-60, for example. Both Cs-137 and Co-60 are gamma and beta emitters, so there is an enhanced level of detection if surface and volumetric monitoring are employed.

INFORMATIONAL REQUIREMENTS FOR MONITORING PLANS

There are three dimensions, representing three unknowns, associated with monitoring plans for disposal of BRC wastes:

- If volumetric monitoring alone is performed, concentration of activity is unknown;
- If surface monitoring alone is performed, total activity (or bulk properties) is unknown; and
- There is unknown measurement error in the monitoring instrumentation and monitoring process.

The natural distribution of activity (i.e. variability) in candidate waste streams for BRC disposal can be modelled by specifying the shape and parameters for two probability distribution: one for contamination concentration (i.e., concentration of activity per unit area), and one for total radioactivity. Assuming that, as with most other natural phenomena, contamination is distributed lognormally, with most items uncontaminated and a few items at increased levels of contamination, these distributions appear as in Figs. 1 and 2. While nCi/gram is the measurement unit shown for contamination concentration, nCi/unit area could serve equally well to represent spacial distribution. Items at the left end of the distribution represent diffusely contaminated material while items on the right represent point source contaminated material.

If no errors in measurement were involved and these distributions were known, BRC limits could be established

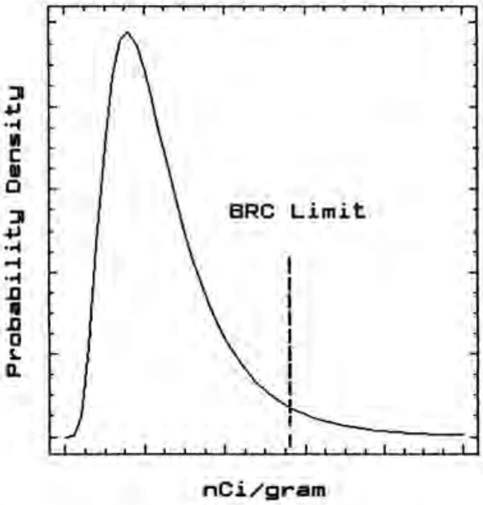

Fig. 1. Distribution of Concentration of Activity in Waste Streams.

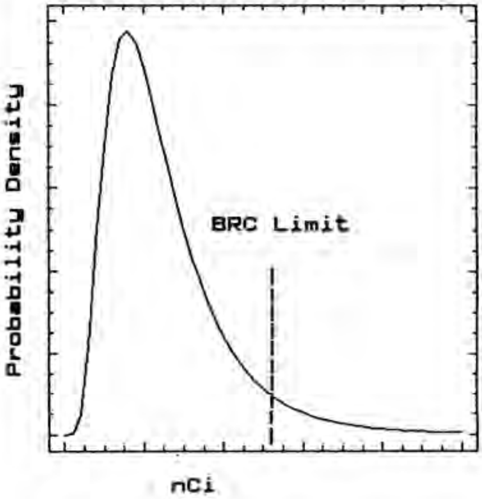

Fig. 2. Distribution of Total Activity in Waste Streams.

such that a small proportion of items would fall above the limits and need to be rejected, either on a concentration basis and/or a total activity basis, while the majority of the items would be accepted as BRC.

Unfortunately, such stable and known distributions do not exist. Sets of distributions would be required if the processes that generated the contamination were subject to anything other than random variation. Natural fluctuations in radioactivity can cause multiple readings from the same source, an independent source of variation. If histograms of actual readings from the measurement equipment were used to estimate these distributions, measurement error would be a third source of variation. The "observed" distributions might look like very different from the true distributions as shown in Fig. 3.

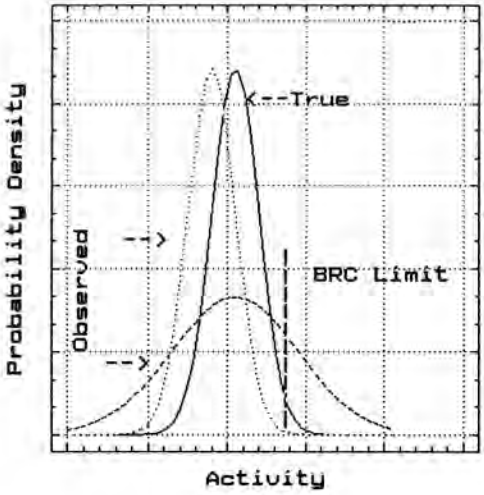

Fig. 3. Effect of Increased Variability and Shifted Mean in Distributions.

Increasing the variation in the observations causes the tails of the observed distribution to spread out, resulting in a greater proportion of the observed measurements to be in the tails of the distributions. The same BRC limit would result in a greater rejection of items based on their observed measurements. The increased variation would increase the confidence limits on the averages, or expected values, of the activity in the wastes. Alternatively, if the observed distributions were shifted to the right or the left (as shown in Fig. 3) due to increased sensitivity of instruments, calibration problems, or background changes, applying a fixed BRC limit to the observed distribution could lead to misclassification of wastes.

Measurement Error

Two characteristics of measurement error are of interest, accuracy and precision. Activity readings on identically contaminated pieces of DAW may not be identical (referred to as imprecision or variation). Readings may not be centered on the true activity (inaccuracy or bias). Imprecision results in larger standard deviations, inaccuracy results in shifted averages.

There are two types of errors, Type I where clean material is rejected as contaminated (also called false negatives), and Type II were contaminated material is accepted as clean (called false positives). Setting higher tolerance limits on detection equipment reduces Type II errors at the expense of Type I errors.

Volumetric Monitoring only: Unknown Concentration of Activity

If volumetric monitoring only is performed, a contamination concentration distribution (Fig. 1) must be known or estimated in order to release BRC material based on a BRC concentration limit. If such a distribution were known, then by simply measuring the total activity in a bag of DAW, and knowing the weight of the bag, a test of a hypothesis could be made that the bag came from the same population as that represented by the known standard surface distribution of contamination. If the bag passed the test, it could be determined, with some degree of confidence, that the bag would contain no more than x% of material above the surface contamination BRC limit. Potential BRC regulations may specify that x must be zero, or x may be set at a very small number. If the bag could not be judged to come from the known population, no surface contamination determination could be made.

The standard contamination concentration distributions would need to be adjusted to each unique plant's conditions. The finer the classification of wastes, the better and more reliable the test of the hypothesis. Plants choosing to use volumetric monitoring alone could need to stratify the population of wastes so that wastes are more homogeneous within strata. This would facilitate the testing procedure but increase the information required on contamination concentration distributions.

Surface Monitoring only: Unknown Total Activity

If surface monitoring only is performed, a total activity distribution (Fig. 2) must be known or estimated in order to release material on a possible bulk properties limit. A second type of test of hypothesis would be required. Based on the combined information of surface contamination seen on individual pieces in a bag, a judgement must be made whether the pieces are from the same population as that represented by the known total activity distribution. If the bag passed the test, it could be determined that no more than y% of the bags have total activity above the BRC limit. Again, y may be set at zero or at a very small number.

Due to the increased likelihood of measurement error with surface monitoring equipment, a confidence interval for the surface measurements should be used in applying the distributional form test of hypothesis. Again, stratification would be important for refining the discriminatory powers of the test.

Combined Monitoring

There are a number of advantages to a combination of surface monitoring plus volumetric monitoring from a statistical reliability perspective.

First, dual monitoring reduces the need for known standard distributions of activity. If a plant is unable to develop known standard distributions, and/or is unable to develop tests that can accurately discriminate between populations, a dual process is required. With an actual measurement on both total activity and contamination concentration of every piece of DAW and every bag, the only variable to cause false negatives or false positives would be measurement error. Over time, making replicate measurements, accuracy and precision could be estimated and systematically reduced using stratification and instrument tolerance adjustments.

The sequential process of allowing only bags that passed the first monitoring technique to be processed through the second would eliminate the upper tail, high activity pieces, of the observed distribution. The distribution passed to the second monitoring technique would be truncated, thus allowing a more accurate and precise second test.

Second, dual monitoring covers the overlapping isotopes discussed earlier. For many isotopes, the probability of detection increases with dual monitoring because the ability to detect gamma and beta radiation is a function of the energy of the emitted radiation. This reduces the measurement error of the machine for higher energy radiation, i.e., the efficiency of the monitor increases with photon or beta energy.

SAMPLING PLAN DESIGN

If it is determined than BRC candidate waste streams are characterized to a known and stable level, sampling at less than 100% may be sufficient to qualify wastes for BRC disposal, at a given level of confidence. Sampling of wastes can be done for two purposes: 1). To provide information on waste parameters for an entire populations (such as means, standard deviations, ranges) based on single samples; and 2). To set up an acceptance sample plan whereby whole lots of wastes are accepted or rejected based on the condition of one sample of size n. This dual purpose follows the two types of sampling inspection plans found in standard quality control handbooks (3): sampling for attributes (item is evaluated on a basis of go or no-go), or sampling by variables (item is evaluated along a scale of measurement).

Sampling at less than 100% creates a new set of problems in addition to those discussed under monitoring plans. Sampling magnifies most of the monitoring problems because estimation of population parameters from sample statistics is very sensitive to variability in sample results. Sampling creates its own set of false positives and false negatives. Measurement error, added on top of sampling error, can render a sampling plan useless. The selection of a dual, sequential monitoring plan is almost a requirement for instituting a less than 100% sampling plan if the sampling plan has very tight requirements.

A complete introduction to sampling plan design is beyond the scope of this paper. Presented below is a discussion of some of the issues involved in designing a sampling plan for disposal of BRC wastes.

Definition of Contaminated Wastes

After measurement by a single or dual monitoring technique, wastes should be unambiguously classified. The selection of an attributes or variables sampling plan will determine the level of measurement required to make this determination.

Selection of the Population to be Sampled

Results from a sample apply only to the population from which the sample was selected. If stratification is performed, results from one subpopulation should not affect the acceptance criteria of a second subpopulation. The exception to this is when it has been determined that there has been a change in the process of contamination affecting all subpopulations, and adjustments need to be made in all acceptance criteria.

Randomization

Randomization requires that every element in the population has an equally likely probability of being chosen for the sample. The operating characteristics of a sampling plan are derived under the assumption of random sampling. Non-randomness may cause the necessity for shredding or mixing to insure a homogeneous, representative sample.

Desired Level of Protection

An ideal sampling plan would have the property that if the number of contaminated items in the population is less than the allowable limit, the acceptance probability would be 1.0. If the allowable limit were exceeded, the acceptance probability would be 0. Achieving this would require a 100% sample, and with sampling error and measurement error, even this would not be enough. Thus, sampling requires that some level of probability be assigned to Type I and Type II errors. Specification of these errors is done when the acceptance and rejection numbers are set.

Desired Level of Accuracy

The closer the actual activity measurements are to the BRC limit, the more the required accuracy of the measurement process, and the more sample items required. There are formulas that specify sample size based on desired levels of accuracy, estimate of variability, and desired level of protection from "unlikely" samples. For proportions and attributes sampling plans, as long of the proportion of contaminated items in the population is between .30 and .70 percent, sample sizes remain relatively constant. When a sampling program is asked to identify rare items , sample sizes quickly increase to 100%. Stratification can help by separating the population into subpopulations.

Measurement Error

To gauge the effects of measurement error and to compensate for them requires the probabilities of these errors be known. These cannot be known unless the true distributions of contamination are known. Adjustments to sampling plans have been proposed to correct for measurement error (4). It is possible to increase sensitivity of the instruments to compensate for measurement error, as discussed earlier.

Attributes vs. Variables Sampling Plans

Attributes sampling plans would be instituted to control the proportion of contaminated items in the wastes to be disposed. If zero contaminated items are permitted to be disposed, 100% sampling, plus dual monitoring with high sensitivity would be required. If a very small percent of contaminated items are to be permitted in the disposal quantities, then an attributes plan can use the definition of percent contamination allowed (called the AQL), and the definition of the percent contamination not allowed (called the LTPD), along with the acceptable levels of probability of Type I and Type II errors, to arrive at an acceptance plan (sample size, acceptance number, rejection number) that will meet these requirements. The true distribution of activity in the population (i.e., the true proportion P of contaminated items) need not be known. If P can be estimated, sampling plan numbers can be modified to obtain as close to a perfect Operating Characteristic curve (a step function at P) as possible with the minimum sample size. An attributes plan would be instituted if the BRC disposal limit were in terms of percent contaminated items allowed in disposed quantities.

When measurements of activity are stated in terms of their actual values rather than "contaminated or not contaminated", attributes plans can still be used by using a classification system. However, considerable savings in sample size may be achieved in applying a variables plan directly to the measurements themselves.

Variables sampling plans are used when the primary interest is in the level of contamination rather than the percent contaminated. Variables plans involve a comparison between a statistic (such as the mean) computed from the sample, and a limiting value (acceptance value) to determine whether the entire lot is contaminated. Variables plans can also be used to control waste stream parameters to given levels; such plans do not necessarily require detailed knowledge of the shape of the underlying distributions of activity. A variables plan would be instituted if the BRC limit were in terms of an average, range, or level of variability allowed in disposed quantities.

Quality control books have volumes of tables that can be used to design attributes or variables sampling plans to the user's specifications.

In summary, it has been shown that choosing between surface or volumetric monitoring equipment for a proposed BRC disposal program depends on what additional information is available, or can reasonably be estimated, on the total amount or the concentration of activity in the wastes. If additional information is not available, a dual monitoring process is preferred on the basis of statistical reliability. If the information is available, and/or a dual monitoring process is instituted, it may be possible to gain statistical control of the waste disposal process with something less than a 100% sample.

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