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Statistics for Environmental Transuranic Studies

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COMMENTS ON 1ST ISSUE OF TRAN-STAT

I was pleased to receive several comments concerning the 1st (September 1977) issue of TRAN-STAT. Two people were particularly pleased that some new statistical references were included. One person expressed the hope that someday the statistician will be as interested in the quality of sampling and analysis as he is about unique ways to display data. This looks like an interesting topic for discussion. It suggests to me the possibility that a future issue of TRAN-STAT might be devoted to discussing the role of the statistician in environmental transuranic studies.

SOME STATISTICAL ASPECTS IN THE EVALUATION OF ENVIRONMENTAL TRANSURANIC CONTAMINATION FOR POSSIBLE REMEDIAL ACTION

In this second issue of TRAN-STAT we discuss some statistical aspects surrounding the question of whether an area contaminated to some extent by transuranium elements requires some type of "remedial action" to guard against a possible health hazard to man. We assume that an upper limit on the level of contamination in soil has been set and that the main problem is to collect environmental soil samples in order to make a decision whether the area being sampled does exceed (in some sense) the agreed upon limits. Of course, decisions might (perhaps should) be made on the basis of an upper air concentration or on the estimated dose to man from living in or near the area. We do not discuss these more complicated situations here, but a recent book by Noll and Miller (1977) discusses the design of air monitoring networks for measuring pollution, including some statistical aspects. Some of their discussion is applicable to the design of soil sampling plans over a geographical region. No attempt is made here to give detailed discussions of the various statistical approaches presented below. Our goal is to present major concepts and to provide you with references that give the details.

SPATIAL PATTERNS

The number and location of soil samples are important aspects of an environmental sampling program. Most general statistics textbooks discuss approximate methods of determining the number of samples, but give little or no attention to the spatial orientation of samples or how spatial data are to be analyzed. Two statistical references that discuss the design and analysis of spatial data in the field of geology are Koch and Link (1970) and Davis (1973). Much of the experience gained in that field might be useful for designing field transuranium studies.

The amount of plutonium in soil is known to vary a great deal from sample to sample. This variation is due to a number of causes that need not concern us now. The important thing is to recognize that a knowledge of the spatial patterns of plutonium concentrations is necessary to design an effective sampling network for making decisions regarding remedial action. In addition to knowledge about general trends and patterns, we also need information on the variability within each general level of contamination and on the extent to which sample concentrations may be correlated with one another. One summary of this variability and possible correlation structure over space is given by the semi-variogram as discussed by Barnes, et al (1977) relative to plutonium concentrations in soil. By structure we mean that concentrations in adjacent soil samples in the field may be related to some extent, but that as soil samples are placed further apart the observations become unrelated. The semi-variogram is a tool for obtaining weighted averages using a technique called Kriging, which is discussed, e.g., by Barnes, et al (1977) and Davis (1973). The applicability of Kriging to environmental plutonium concentrations is currently being investigated by Dr. Pam Doctor at BNW, Ms. Madaline Barnes (Desert Research Institute, Las Vegas) and Dr. Pierre Delfiner (Center for Geostatistics, School of Mines, Fontainebleau, France) and perhaps by others. The "conventional" methods discussed below all assume that no correlation exists.

DECISION ERRORS

All methods discussed in this issue involve the specification of two types of errors that can be made when deciding whether a specified land area being sampled requires action. These are:

- (a) taking remedial action when none is required, and
- (b) not taking remedial action when such action should be taken.

These two types of errors are referred to by statisticians as Type I and Type II errors respectively. In practice we can never be absolutely sure that we have not made one of these errors since we can't sample the entire area, i.e., our samples provide only partial knowledge of the level and extent of contamination. In the absence of complete knowledge there is always the possibility of error. A statistical problem is to determine the number,

type, and placement of samples to insure that the probability of making these two types of errors is not too large. To our knowledge no one has given much thought to the size of acceptable probabilities of making Type I and Type II errors. This should be done, however, since the number of samples to be collected depends in part on the specification of these probabilities. The specification of Type I and Type II error probabilities requires evaluating the consequences of making either of the wrong decisions. Taking remedial action when it is not required results in unnecessary monetary, environmental, and social costs. Not taking remedial action when a real potential health hazard exists has its own potential costs built into the situation. Another important point is that collecting only a few samples when variability between samples is high will tend to result in large probabilities of making Type I and Type II errors, whether or not this is formally recognized as being a consequence of that sample size decision.

SOME CONVENTIONAL STATISTICAL APPROACHES

In the remainder of this issue we briefly discuss some conventional statistical approaches that, if certain assumptions are met, might be applicable to the question of whether remedial action is required. An assumption common to all approaches is that representative samples be drawn from all portions of the area being investigated. Random samples within subunits of the area would be one way this could be accomplished. Sampling on a grid system might also be acceptable if it can be assumed that no systematic bias will be introduced. Some approaches assume that data are lognormally distributed; others assume that the mean of the data is normally distributed with known standard deviation. Another assumes the individual data points themselves to be normally distributed, and some methods require no distributional assumptions.

The occurrence of unknown "hot spots" within a field of low concentrations is a problem for all methods. These should be uncovered, if possible, by portable field instruments or other means before major sampling for possible remedial action begins. The occurrence of strong concentration gradients within the sampled region can also affect the performance of the statistical approaches discussed below. This suggests the importance of determining the general pattern of concentration levels over the region before the sampling design is decided upon.

In the following discussion we presume that a decision regarding remedial action is to be made for a unit of land from which samples are to be collected. The decision making process should take into account the inherent variability in concentration levels from sample to sample. Two basic approaches are briefly discussed. The decision could be based on (1) the average concentration obtained from n representative samples or (2) on the proportion of sample concentrations greater than some specified concentration (the attribute approach).

(1) Average Concentration Approach: Known Standard Deviation (σ)

Assumptions: Normally distributed mean concentrations; random samples.

The assumption of a known standard deviation (σ) make this approach somewhat unrealistic in most if not all situations. Transforming

to logarithms and performing calculations in log scale may help circumvent the normality assumption. (The approach in (2) below does not require σ to be known). A limiting soil concentration (μ_1) is specified, where μ_1 is an average concentration (of a normal distribution with standard deviation σ) that has been judged not to constitute a potential hazard to man. It is also necessary to specify the desired probability (α) of a type I error i.e., of wrongly concluding that the unit needs remedial action, and the probability (β) of a Type II error, i.e., of wrongly concluding that remedial action is not necessary. (In other areas of application α and β are commonly set at .05 or .10 [5 and 10 percent]). In addition, if we can specify an average soil concentration μ_2 (greater than μ_1) that does constitute a health hazard and hence is important to detect, then we can estimate the number of samples (n) that should be collected within the unit in order to have a probability of $1-\beta$ of detecting a mean soil concentration as large as μ_2 . The n samples are collected and the average, $\bar{x}$, and the quantity $K = \mu_1 + (Z_\alpha \sigma / \sqrt{n})$ is computed, where Z_α is the normal deviation that cuts off α percent of the upper tail of a normal distribution (e.g., $Z_{.05} = 1.645$). Then $\bar{x} > K$ implies remedial action, while $\bar{x} \leq K$ implies no remedial action (Burr, 1976, pp. 325-328).

Note that this approach assumes the mean $\bar{x}$ is normally distributed which will be assured if the individual data points are normally distributed, and may be approximately true if the data are not badly skewed. If the data are badly skewed then the procedure might possibly be applied to the logarithms of the data since these should be nearly normal in distribution. In this case μ_1 , μ_2 , and σ would need to be specified in logarithmic units also.

(2) Proportion Approach: Unknown Standard Deviation

Assumptions: Independent, normally distributed data; random samples.

If σ is not known (the usual situation) a different procedure from that discussed in (1) above is possible, the validity of which depends more critically on the assumptions of normality (Burr, 1976, pp. 332-334). The individual data points must be normally distributed, whereas in the above case (where σ was assumed known) only the mean $\bar{x}$ needed to be normally distributed, a more likely situation in practice. As in (1) above we must specify α and β , but we need not specify σ . Instead of μ_1 and μ_2 we specify p_1 and p_2 , where p_1 is a proportion of samples with concentrations greater than some level U that is judged to not constitute a health hazard, and p_2 is a proportion of samples with concentrations greater than U that does constitute a health hazard ($p_2 > p_1$).

The number of samples (n) to collect in the cleanup unit can then be estimated using equation (11.17) in Burr (1976, pp. 333). We decide to take remedial action if $\bar{x} + ks > U$ and not to take remedial action if $\bar{x} + ks \leq U$, where $\bar{x}$ and s are the average and standard deviation of the n concentrations, respectively, and k is a constant computed using equation (11.16) in Burr (1976, p. 333).

Both approaches discussed in (1) and (2) above make use of the mean $\bar{x}$. We note that a mean concentration can be diluted (made smaller) by including areas of low concentrations within the region being sampled that has some high concentration areas or "hot spots". We noted above the importance of identifying these high concentration areas so that they could be more extensively sampled or handled separately from lower level regions.

(3) Attribute Approach:

Assumptions: No statistical distributional assumptions required; random samples.

The attribute approach to deciding whether remedial action is required is based on a specification of α , β , p_1 and p_2 , but the assumption of normality is no longer required. Using Burstein (1971, Table 13) we can determine the number of samples n and a "rejection number" r . If r or more of the n samples have activities greater than U , then the decision to take remedial action is made. This method is also discussed by Burr (1976, Chapters 9 and 10) and Saltzman (1972, pages 94 and 95).

The attribute approach is used mainly in industrial applications where a small fraction of defective product items can be tolerated. Translating it to an areal sampling problem is subject to some questions. Note, for example, that one might sample a very large area that is very highly contaminated in only a small subarea. Any practicable sample size would undoubtedly "pass" the large area, even though a few samples fell in the highly contaminated area. If one looks at the data, the existence of the highly contaminated area will be recognized. It should be noted that the attribute approach does not do that. It only considers fractions of the samples that are above or below the criterion U . Saltzman (1972) makes a point of the importance of a random sampling program for the attribute approach to yield valid results.

(4) Sequential Approach:

The approaches mentioned in items (1), (2), and (3) above assume that the remedial action decision is made on the basis of n samples collected at a single stage or time. A more general approach is a sequential sampling plan where a number of initial samples are gathered and their concentrations determined. Then one of three decisions is made: (1) remedial action is required, (2) remedial action is not required, or (3) take more samples before deciding one way or the other. Burr discusses these plans

in Chapter 12 for the situation where σ is known. See National Bureau of Standards (1951) when σ is unknown. Any of the approaches discussed in items (1), (2), or (3) can be done sequentially. This kind of approach seems natural in the sense that seldom can we design a single stage (nonsequential) sampling plan that will provide sufficient information upon which to make a decision.

(5) Other Approaches:

In some situations a considerable amount of data may already exist for some geographical region. Hence, it may be desired to estimate confidence intervals for mean values, to estimate the proportion of the population exceeding a specified concentration, or to place confidence intervals on the proportion. Saltzman (1972) gives simplified nomographic methods for these purposes if the data follow precisely the normal or lognormal distributions. He also discusses the need for random samples and points out some of the problems involved when trends are present over space and time. Hale (1972) presents a simple method of determining the number of samples needed to obtain upper and lower bounds for the geometric mean of a lognormal distribution.

FINAL COMMENTS

Your comments on this issue are encouraged, so please write or phone. We would like to have your ideas on other statistical approaches for making decisions regarding remedial actions.

ACKNOWLEDGMENTS

I would like to thank Pam Doctor and Tony Olson (both of BNW) for their constructive criticisms of an earlier draft of this issue of TRAN-STAT. Lee Eberhardt (BNW) also contributed to this issue.

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