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GENERAL STATISTICAL CONSIDERATIONS

by

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ABSTRACT

The high sampling variability encountered in environmental plutonium studies along with high analytical costs makes it very important that efficient sampling plans be used. However, efficient sampling depends on explicit and simple statements of the objectives of the study. When there are multiple objectives, as in the NAEG study, it may be difficult to devise a wholly suitable sampling scheme. Sampling for long-term changes in plutonium concentration may also be complex and expensive. Further attention to problems associated with compositing samples is recommended, as is the consistent use of random sampling as a basic technique.

Introduction

This report is concerned with some general considerations having to do with the quantitative aspects of environmental plutonium studies. A longer and more detailed analysis is being prepared as a separate report, and the particulars of our statistical work on NTS soil samples appear under another heading in this progress report.

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The high variability from sample to sample and the considerable cost of accurate plutonium analyses make it essential to seek out and use efficient sampling procedures. Much of the relevant statistical sampling methodology can simply be described as procedures for satisfying particular objectives at a minimum cost. An important problem in environmental plutonium studies is that the objectives of such investigations may not be specified at all clearly, or may be multiple and complex in nature. There is thus a need to try to pin down these objectives and to see whether suitable sampling procedures can be devised and executed in the field.

Material and Methods

Our interest in the quantitative aspects of environmental surveys for plutonium contamination initially arose in connection with studies at the Nevada Test Site under the auspices of the Nevada Applied Ecology group. Our main effort thus far has been concerned with statistical aspects of sampling soils for plutonium, and some preliminary details appear in a report by Eberhardt and Gilbert (1972). We were also asked to make some suggestions about statistical aspects of a survey for plutonium on Eniwetok Atoll, and have benefited from the opportunity to visit and discuss environmental plutonium studies at Los Alamos and Colorado State University. The methodology involved here largely depends on the statistical technology developed for survey sampling, as described for example by Cochran (1963). We have also depended on results concerning the lognormal distribution summarized by Aitchison and Brown (1966)

Unfortunately, the best-developed statistical technology has to do with estimating specific quantities of some substance, while the compelling issue in connection with plutonium has to do with the much less precisely defined objective of protecting people from harmful exposures. Our approach to that question is predicated on the assumption that the only sure protection is a thorough knowledge and understanding of the fate of any plutonium introduced into the environment. Since the routes and processes involved are many and may be complex, we suspect that effective planning requires a fairly comprehensive model of some kind. One strong reason for this notion is the frequently mentioned point that most of the field experience with plutonium is in arid areas so that the results may not be appropriate for application in the case of accidental dispersion of plutonium in, say a midwestern agricultural area, or an eastern suburb. We contend that one useful way to clarify the points of commonality and dissimilarity is to try to make explicit the details of such an incident in a model.

We hold the view that models are useful for appraising and summarizing data, exploring objectives, and designing field and laboratory studies. In the present state of knowledge about environmental contamination, we do not believe models are very useful for numerical prediction--where extrapolations must be attempted we suspect regression techniques (preferably based on a specific model) are to be preferred.

Results and Discussion

One source of potential confusion in sampling soil for plutonium hinges on use of the word "inventory." In everyday usage, an inventory is normally taken to mean a complete accounting of some items of interest. One then assumes not only that we know how many items there are, but also exactly where the individual items are located. When inventories are taken by sampling, information on location may be sacrificed in the interest of obtaining a precise estimate of total quantity.

When the objectives of sampling for plutonium are considered in the light of problems like dose-assessment, determining "source-terms" for resuspension studies, or setting limits for "clean-up" operations, it may well be that information on location becomes more important than a good estimate of total quantity.

The soil sampling done thus far (area 13 and the GMX site) has been based on stratified random sampling, in which proportionately more samples go into the subareas (strata) having the higher plutonium concentrations. Since both of the areas now being sampled were contaminated from a single location, and plutonium concentrations seem to drop off fairly smoothly towards the boundaries of the area, we are inclined to believe that the present sampling scheme will be reasonably efficient for "location" purposes. However, it seems important that there be some further discussion of the relative importance of estimating totals versus location before sampling plans are decided on for other areas.

We have not as yet been able to locate references on sampling theory specifically directed towards the questions posed here, although there are various fields of statistical study that seem to "come close" to the problem. One common-sense approach is to use a uniform ("grid") spacing of sample plots and to fit contour lines, possibly using one of the computer routines devised for that purpose. One major drawback to such a scheme is that it will clearly result in over-sampling the low concentration areas, and thus not be at all efficient.

Our discussion of sampling thus far has been couched largely in terms of a static situation, as though the material being studied were fixed permanently in place. For many of the objectives of soil sampling, this is a reasonable assumption. In the long term, however, we do need to consider how to measure changes. Several possibilities can be considered:

1) Later transport by water (movement down a "wash," for example).

2) Penetration into the soil.

3) Gradual dispersion along soil surfaces, as the result of wind movement.

4) Local accumulation areas (as in soil mounds under bushes at NTS).

Other prospects need to be considered, too. Those listed above mostly occur over long enough spans of time to make sampling for changes very difficult, particularly for plutonium, due to the high variability of sample results. At the moment we are mostly considering prospects for obtaining some rough notion of approximate dispersion rates, but very likely should also consider sampling plans that deal directly with change in time.

In the NAEG study there evidently is some degree of surface movement of plutonium from wind action. Details of this change are under study in the resuspension program. Typically, one of the "safety shot" areas may show concentrations that decrease in all directions from the site of the explosion(s). We have suggested visualizing a three-dimensional plot of concentrations as a smoothly-shaped hill. Generally such a hill-shaped representation will be considerably elongated in the downwind direction of the prevailing winds.

We assume that the major part of the dispersion of plutonium in these sites takes place at the time of the original "event" (explosion(s) in the safety shots). After the event, there apparently is a gradual outward dispersion of material in the surface layer of soil. In the downwind direction, this presumably results in the gradual apparent reduction of concentrations; in effect, the "hill" of concentration tends to become lower but broader and longer. One particularly interesting question about such changes is what they mean in terms of the exposure of plants and animals to plutonium.

Presumably an increasing number of individuals are exposed to a decreasing average concentration. The presence of local accumulations under desert shrubs has already been mentioned.

The other source of reduction in surface concentrations is possible penetration of plutonium into deeper soil layers. The available soil profile data often suggests an expontially declining concentration with depth, as would result from a diffusion model. One is thus tempted to assume a constant relationship between depth and time, and to try to deduce an average rate of penetration. The effects of wind and water rearrangement of surface soil layers may be important in this context, but beyond some indefinite depth the net effect is presumably one of removing plutonium from possible resuspension. Just what bearing this has on plant uptake is of interest, too. Presumably shallow-rooted plants will have less access to plutonium over time, but shrub root systems may have an interesting contact. Although plant uptake is known to be small, its net effect is always towards bringing the material back to the soil surface. Hence there is an evident need to try some quantitative appraisals of balance between diffusion downwards and return by plants.

Since the possible movements in soil are evidently quite slow, an unreasonably large amount of sampling will be needed to obtain useful estimates of rates in relatively short time periods. Also, we do not, at present, have a clear notion as to the best sampling scheme for that purpose. It thus seems extremely important to look for historical data that can be used to help infer rates, and, if necessary, to plan sampling schemes. Because there are often doubts expressed about validity of some of the older analyses for plutonium, it would be particularly useful to obtain the actual soil collected a number of years ago, and to compare analyses on such samples with current samples from the same site.

One important and as yet unresolved problem concerns the advantages and disadvantages of compositing or "pooling" samples. Two purposes may be suggested:

1) To achieve a sufficient mass of, for example, tissues of small animals to permit analysis.

2) To attempt to reduce variability by combining a number of samples taken in the same neighborhood.

A further complication is introduced in cases where a set of samples are combined, but only a fraction (an aliquot) is used for the actual analysis.

We are not presently prepared to offer complete recommendations as to how to handle this problem, but bring it up for two reasons. One is to note that answers will depend very much on objectives and the other is to suggest that the results of some experimental studies would be most helpful in unravelling the tangle. We believe that some of the results of the study by Eberhardt, et al., (1973) may be helpful in appraising such studies, but as yet have not located appropriate data for analysis.

When the entire composited sample can be analyzed, and the primary objective of the study is to estimate a total or a mean, there doesn't seem to be any major problem for something like soil sampling. We do recommend, though, that the sampling design specifically take into account compositing, by using "cluster" sampling. One such procedure is to define large sampling units ("primary sampling units"), draw a random sample of smaller plots (e.g., soil cores) as "elements" within each such primary sampling unit. The elements can then be composited, and the composite value used to represent each primary unit which is now essentially treated as a single sampling unit. The main question about such a procedure is whether or not it yields any worthwhile reduction in costs.

When aliquots are taken from a composited sample, prudence dictates that two separate subsamples be taken from each composite to determine whether the mixing is effective, and thus whether or not the compositing is really worthwhile.

We have been pretty consistent advocates of the use of random sampling for soil plutonium studies. We have recently been reminded of some applications (the global strontium-90 and similar surveys) that have produced highly satisfactory results by "eyeball" selection of sampling sites. We think it is necessary, however, to consider the circumstances, phenomena, and purposes of the Health and Safety Laboratory (HASL) fallout surveys before extending that methodology for use in some other situations. These include the following features:

1) If only a very few locations can be used for some very large region (e.g., a continent) its unlikely that even the most dedicated statistician will stick to random selection.

2) Apparently the major component of variability in the global fallout surveys is the variation over time. The large-scale physical forces seem to be such that rather large areas receive almost identical increments of fallout (at a given latitude).

3) Soil sampling for global fallout thus requires careful selection of sites that will serve to integrate fallout over time--in a sense to serve as fallout collectors.

Very likely quite similar arguments can be advanced in referenct to appraising fallout on a smaller scale. The most important exception, in our judgement, has to do with circumstances where redistribution (by wind, water, etc.) has to be taken into account. For the main purposes of the global surveys the effects of redistribution constitute a nuisance factor to be avoided if at all possible. For other objectives, having to do, for example, with assessing the current distribution of plutonium on the Nevada Test Site, redistribution must somehow be taken into account. For such purposes, we believe random sampling to be an essential part of a sampling scheme.

A final item that might be mentioned here is the use of double-sampling, wherein an accurate but expensive method is supplemented by an inexpensive but less reliable alternative method of measurement. A detailed discussion is given in our earlier report (Eberhardt and Gilbert, 1973). We only want to note here that further accumulated experience in comparing "FIDLER" results with plutonium analyses by "wet chemistry" continues to suggest that the correlation between the two sets of measurements is not sufficiently high that important gains in sampling efficiency can be made using the two methods. However, correlations between gamma scans and wet chemistry continue to be very high. We should emphasize that the "FIDLER" results are very useful and desirable for stratification and for other purposes.

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