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SOME DESIGN ASPECTS OF TRANSURANIC FIELD STUDIES

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ABSTRACT

In this paper we discuss some design aspects of transuranic field studies. Some of the principal steps in the design of such studies are given and illustrated using examples. This is followed by a review of sampling designs that have been used at nuclear detonation and safety-shot sites on the Nevada Test Site and elsewhere for estimating spatial pattern and total amounts in soil. Some design aspects of ecosystem-type transuranic studies for estimating total amounts as well as movement of transuranics between ecosystem components are also discussed.

Acceptance sampling using either attributes or measurements is considered as a possible approach for deciding whether to clean up a contaminated site. Three general guidelines for the design of efficient transuranic studies are presented.

INTRODUCTION

The design of a transuranic field study depends on a number of factors including objectives, the quantity, kind and properties of the radionuclides present (related to the source of contamination), the spatial distribution of the contamination over the study site (trends, hot spots, etc.), and a variety of practical considerations involving budget limitations, size of the study site, time allowed for the study, etc. As a consequence, field sampling designs are necessarily site specific. However, there are general guidelines that can be used to help design efficient transuranic field studies. These guidelines are based on statistical methodology developed for sample surveys in other areas of application and on experience in designing transuranic studies.
The design of any transuranic study should begin with careful planning well in advance of the actual collection of field samples. The first step is to carefully specify objectives. The second step is to define the "population" to which inferences are intended to apply. When these essential steps have been accomplished, decisions concerning the kind of data to collect, the precision in estimates needed to meet objectives, and the actual sampling locations can be made.

No attempt is made here to provide a complete review of the literature regarding the design of transuranic field studies. However, the references included should illustrate various designs that have been used in past studies. Our discussion of possible approaches to deciding whether cleanup is needed should be considered only as a guide to what might be done in actual practice. To our knowledge, no cleanup operation has yet been conducted using the probability approach described here. Practical problems in the field will require modification of our suggestions.
PRINCIPAL STEPS IN DESIGNING TRANSURANIC FIELD STUDIES

Certain factors should be considered in designing transuranic field studies. The description of these which follows has been adapted from Cochran (1963, pp. 5-8).

OBJECTIVES

Identification of objectives is necessary in order to choose the most appropriate field sampling design (see Eberhardt, 1976 for discussion). Since most studies have multiple objectives a compromise design may be necessary. Some common objectives are:

1. Geographical distribution (spatial pattern) of the contamination over the study site (horizontal and with depth).
2. Inventory (total amount) of contamination present in soil (worldwide fallout or local contamination).
3. Amount of radionuclides present in ecosystem components (soil, vegetation, air, invertebrates, vertebrates).
4. Changes in concentration in ecosystem components over time.
5. Rate of movement of radionuclides from one component to another (soil to vegetation, sediments to water, etc.).
6. Resuspension by wind or from the activities of man and animals.
7. Determination of whether a cleanup operation is necessary or to verify that cleanup has been successful.
8. Evaluation of the hazard to man from a given contamination (this may include all of the above objectives).

POPULATION TO BE SAMPLED

Cochran (1963) defines "population" to be the aggregate from which the sample is chosen. It is important to distinguish between the "target population"
and the "sampled population". In transuranic field studies the target population is that part of the environment about which information is wanted. The sampled population refers to the population from which samples are actually collected. Inferences always pertain to the sampled population. This is an important point since the sampled population may not correspond to the target population. As an example, consider sampling the sediments of a pond known to be contaminated by plutonium. The objective might be to estimate the average Pu concentration in these sediments. The target population could be the sediment layer in all areas of the pond, whereas the sampled population might be restricted to certain portions of the pond due to practical reasons. Since samples are drawn from only the "sampled population", conclusions from these samples may not apply to the sediments in those areas of the pond that could not be sampled.

As another example consider sampling an area contaminated locally by a nuclear detonation or safety-shot test. The "target population" for soil at these sites is usually surface soil (to some specified depth) over the entire site regardless of terrain, rock content of the soil, vegetation cover, etc. Efforts should be made to insure that the "sampled population" is identical to the "target population" so that no portion of the study area is systematically excluded from sampling. For some kinds of field studies this goal may be impossible to achieve. For example, suppose that we wish to estimate the total deposition of transuranics from world-wide fallout since the start of atmospheric testing in 1945. The target population could be considered to be the surface area of the entire world, whereas the sampled population is restricted to land sites that have acted as fallout collectors since 1945. Those parts of the target population not included in the sampled population are bodies of water,
inaccessible land areas such as mountains, locations where transuranics might have accumulated or washed away, or undisturbed sites that could not be sampled due to practical problems or deliberate exclusion.

**DATA TO BE COLLECTED**

Careful consideration must be given to insure that all data required to meet the study objectives will be collected. This step requires a clear understanding of objectives so that all essential information is obtained. It may also be necessary to collect certain data in order to properly interpret other data. For example, if "in-situ" (field) measurement instruments are used it may be necessary to collect additional soil samples to calibrate the in-situ readings with wet chemistry soil concentrations. These special studies may need to be done before the main study begins.

**PRECISION DESIRED**

Any estimated quantity is subject to error since only a small proportion of potential environmental samples can be collected and analyzed. This error can be reduced in a number of ways such as by taking more samples, using more efficient designs and statistical analyses, or using more accurate instrumentation and wet chemistry techniques. Since these techniques usually require additional time and money, the administrator or person who is actually going to use the data should decide on the precision required. Furthermore, this should be decided before the study begins. In transuranic field studies the precision needed to meet objectives may be difficult to define, as for example, when a decision regarding cleanup of a contaminated area must be made. Decisions based on highly accurate and
precise estimates of contamination levels are obviously desirable. However, stringent requirements on precision may increase sampling and analysis costs considerably.

CHOICE OF MEASUREMENT INSTRUMENTATION AND LABORATORY PROCEDURES

A variety of measurement methods have been used in transuranic field studies depending on objectives, budget considerations, variability over space and time, and other factors. Some examples are field in-situ instrumentation surveys, aerial surveys, and wet chemistry or Ge(Li) scan analyses on environmental samples. The choice of instrumentation will also affect our perception of reality. For example, in-situ field gamma counters scan a large amount of soil relative to a 10-gram aliquot being scanned in the laboratory. Hence, the variability between adjacent in-situ readings may be considerably less than that between two 10-gram aliquots from the two scanned areas due to an averaging effect in the field. Each method gives us a different view or perspective on the contamination as it exists in the field. Care should be taken so that the most appropriate instrumentation is used to fit the objectives of the study. For example, an in-situ measurement may be appropriate for establishing general levels of contamination in soil, but inappropriate for detailed study of the relationship between soil and vegetation concentrations.

DIVISION OF POPULATION INTO SAMPLING UNITS

Before sampling begins the population should be divided into sampling units that do not overlap and which cover the population to be sampled. The samples actually collected are drawn from this collection of sampling units.
As a simple example, the ground area of a study site might be gridded (conceptually or on paper) and certain of these grid cells chosen at random from which the vegetation is collected and analyzed for Pu. If changes over time are expected to occur, as for example with resuspension measurements, then the sampling unit might be a unit of space over a specified time period. The totality of sampling units is called a "frame". Conceptualizing the environment as composed of distinct units that fill up the environment but do not overlap can be helpful in the design of field studies because it tends to reduce a complex situation into more manageable distinct sampling units.

SELECTION OF SAMPLES

There are many ways of selecting particular sampling units for collection. These include simple random, stratified random, or systematic designs, as for example, on a grid. The method of choice depends in part on the patterns and trends that are likely to be present over space (or time). For example, if soil is uniformly contaminated in all parts of the study site, then the variance of the estimated average concentration is likely to be similar for any of the above mentioned plans (assuming equal sampling effort). However, if trends in concentration do exist then either the stratified random or possibly a systematic design is likely to result in a smaller variance estimate. The choice between stratified random and a systematic grid system depends on the correlation structure between samples various distances apart. If a considerable amount of data is available, perhaps from a preliminary study, it may be possible to estimate this correlation structure in order to
make an objective choice between sampling plans. A knowledge of spatial
correlation can also be used to obtain better estimates of averages or
totals using an estimation technique termed Kriging (Davis, 1973, pp.
381-390). This technique is also mentioned below in connection with sampling
for cleanup.
REVIEW OF TRANSURANIC SAMPLING DESIGNS

This review is divided into two parts; studies at nuclear detonation or safety-shot sites where the spatial distribution of the contaminants is of considerable importance, and ecosystem-type studies where movement of transuranics between ecosystem components is of primary interest. These two parts are not mutually exclusive, however, since ecosystem studies are usually an important part of studies at nuclear (fission) or safety-shot sites.

LOCAL CONTAMINATION AT NUCLEAR DETONATION OR SAFETY-SHOT SITES

Radionuclide contamination at safety-shot and nuclear detonation sites is generally highest near ground zero (GZ) with the pattern of contamination determined in part by wind speed and direction at the time of detonation, and whether the assemblies of Pu were covered by a steel plate, buried in the soil, etc. Considerable information may be available from in-situ instrument surveys conducted following the shot or prior to the main soil-sampling effort. These advance surveys may serve to define the general level or spatial distribution of radionuclide concentrations over the area. At safety-shot sites (studied by the Nevada Applied Ecology Group (NAEG): see Dunaway and White, 1974; White and Dunaway, 1975, 1976) the FIDLER instrument was used to measure $^{241}\text{Am}$, which at these sites gives a general idea of the $^{239-240}\text{Pu}$ present in surface soil.

Aerial surveys have also been used to estimate spatial distribution. Examples here are the gamma surveys for $^{60}\text{Co}$, $^{137}\text{Cs}$, and $^{241}\text{Am}$ over the islands of the Enewetak Atoll (Stuart and Meibaum, 1973), gamma surveys for $^{137}\text{Cs}$ and $^{241}\text{Am}$ over the Hanford Reservation in 1973 (Bruns, 1976), and an aerial radiological survey of the Nevada Test Site (NTS) (EGG, 1972).
(See Burson, 1974, for recent research progress in airborne surveys). In situations where $^{241}\text{Am}$ and $^{239-240}\text{Pu}$ concentrations in the same aliquot are related, surveys for $^{241}\text{Am}$ hold promise for estimating the spatial pattern of Pu in soil.

Survey information may in some cases be useful for obtaining at least a rough estimate of the Pu inventory. To do so requires estimation of a "calibration" relationship between the in-situ or aerial survey readings and Pu concentrations obtained in soil samples. Gilbert and Eberhardt (1976) evaluated the suitability of estimating Pu in soil aliquots taken from safety-shot sites using FIDLER data obtained at random soil sample locations immediately prior to taking the soil sample. They found the method (termed "double sampling") to be applicable for higher levels of contamination where the correlation between FIDLER readings and Pu wet-chemistry concentrations was sufficiently high and the cost ratio of FIDLER to wet-chemistry analyses sufficiently low.

Once surveys have estimated the spatial distribution pattern, additional survey readings and/or soil samples are sometimes taken along a transect running from GZ down the "hot line" or center of the fallout pattern. Closer spacing between sampling may be used near GZ in order to estimate more accurately the rapid changes in concentration levels likely to occur in that area. This was the general approach used at the NAEG safety-shot sites, the Plutonium Inventory and Distribution Program at NTS (Church et al, 1974; Brady and Church, 1975) and at the Trinity Site in New Mexico (Hakonson and Johnson, 1973). The purpose of such transect samples is usually to gather information to facilitate the design of more intensive studies. Soil samples collected along a single transect are usually too few and widely spaced to be useful for estimating inventory.
If the objectives of the study require additional information on soil concentration there are several design options open to the investigator depending on objectives. If the in-situ or aerial surveys have satisfied the requirements for information on the spatial distribution of contamination, then soil samples may be collected primarily to estimate inventory. In this case the survey information may be useful for stratifying the study site within which soil samples are collected. The idea of stratification is to enclose areas of different concentration levels into separate strata (sub-areas) so that the variability between samples within strata is as small as possible relative to the variation between stratum means. If the sample locations within strata are chosen at random this design is termed stratified random sampling (Cochran, 1963). Stratified random sampling was used at the NAEG safety-shot sites (Gilbert and Eberhardt, 1974; Gilbert et al., 1976a) and tended to result in estimates of inventory with smaller standard errors than if stratification had not been used (Gilbert et al., 1975).

If in-situ or aerial measurements are not sufficiently well correlated with soil concentrations, or if such surveys have not or cannot be done, the design of the intensive soil sampling plan may need to fulfill the two objectives of spatial distribution and inventory. One approach is to arrange a rather fine grid over maps of the study area and to choose at random a number of squares defined by the grid. This approach was used for sampling soil on most islands in the 1972 Enewetak Radiological Survey (Lynch and Gudikson, 1973). The selection process can be performed using a random number table such as produced by the Rand Corporation (1955), or by using a good
pseudo-random number generator on a computer. The locations actually sampled would be the centers of the randomly chosen squares.

An alternative design would be to first stratify the area based on \(^{241}\text{Am}\) Ge(Li) scans on soil samples collected on a grid. Once the strata are determined a grid within each stratum (grid size need not be the same for all strata) could be established. Then two or more locations could be chosen at random within each grid square in each stratum.

The above discussion has concerned contamination from local sources. In this situation it is usually best to avoid sampling at only "undisturbed" locations, since these locations may not be representative of the area (Eberhardt, 1976). However, when estimating total deposition from world-wide fallout, it is common to sample only undisturbed sites (Hardy and Krey, 1971). The distinction is whether interest centers on estimating the existing spatial distribution and inventory or on estimating the total amount deposited over time. Undisturbed sampling locations have also been used to estimate the spread of contamination from the Rocky Flats plant (Krey and Hardy, 1970). The issue involved here is important for other study objectives, also. Consider a study for evaluating the need to clean up an area. In terms of potential health risk it may be more important to determine where most of the contaminant is presently located than to know only the total amount initially deposited.

**SAMPLING TO ASSESS RELATIONSHIPS**

After information has been obtained about the spatial distribution of transuranics, there may be interest in estimating the amounts of contamination
in various ecosystem components and the movement rate of transuranics between components. The design of these studies depends to a large extent on the particular ecosystem being studied. The design of such studies should be based on whatever information is available or can be obtained on where the bulk of the contamination is located and how this contamination is likely to move through the environment.

Three ecosystem-type studies may be briefly mentioned. These include NAEG studies in Nevada at 10 safety-shot sites referenced above. Soil and associated vegetation samples were collected at all 10 sites according to a stratified random sampling plan. Small mammals were also collected at some sites, and in Area 13 (Project 57) cattle were grazed in the Pu contaminated areas to obtain information on uptake and tissue distribution of Pu due to grazing a contaminated area (Smith et al, 1976). An important objective of these NAEG studies is to evaluate the potential hazard to man from this contamination. A provisional Pu transport and dose estimation model has been developed for this purpose by Martin and Bloom (1976). Gilbert et al (1976) gave an initial synthesis of the Area 13 Pu data for soil, vegetation, small mammals, cattle, and a "hypothetical man". Other transuranic ecosystem studies include those at the Savannah River Plant and in some of the canyons at Los Alamos. At Savannah River (McLendon et al, 1976), samples of soil, a resuspendible fraction of soil, vegetation, grasshoppers and cotton rats were collected and their Pu (238Pu, 239-240Pu) concentrations compared in order to study the transport of Pu in a humid climate. The primary objective of the
Los Alamos studies (Hakonson et al., 1976) was to estimate the $^{238}\text{Pu}$, $^{239-240}\text{Pu}$, and $^{137}\text{Cs}$ levels in canyon ecosystem components (stream sediments, vegetation, small mammals) as a function of distance below waste discharge areas.

The design of such studies is complicated due to incomplete knowledge of how transuranics move through the environment and of the spatial patterns and correlations over time and space. Under the assumption that samples collected near each other are more alike than those from further apart, the collection of adjacent soil and vegetation samples is often practiced. However, Gilbert et al., (1975) illustrate that in desert environments the correlation between Pu concentrations in such "paired" samples is often low. In a desert environment where resuspension plays an important role in determining vegetation concentrations, differences among species have also been found (Romney et al., 1975). This suggests the need in such an area to avoid lumping species together when computing average concentrations or correlation coefficients. The design of small mammal studies is complicated by a lack of close correlation (at least in desert environments) between concentrations in animal tissues and those in surrounding soil. Designs for these kinds of studies must consider those variables that might account for the observed variation. Thus it might be possible to stratify over time, space, species, depth of soil, weather conditions, etc., in order to estimate the components of variance.
SAMPLING FOR CLEANUP

There have been a number of instances where cleanup operations or decontamination procedures have been undertaken to remove or stabilize radionuclide contamination in soil. Wallace and Romney (1975) discuss the procedures and experience gained at a number of locations and give an extensive reference list. A companion reference is Rhodes (1976) who gives a position paper on treatment of certain Pu contaminated areas on the Nevada Test Site. Our concern here is with the elements of a sampling program that might be applicable to the question of whether a cleanup operation is required.

Two sampling approaches under the general title of "acceptance sampling" are presented below as possible procedures for deciding whether cleanup is required. Only the bare essentials are given here. Setting up these plans would require attention to many design details. The two approaches are called acceptance sampling by (1) attributes and (2) measurement. We begin with acceptance sampling by attributes.

A criterion for deciding when cleanup is required might include an upper limit on soil concentrations that should not be exceeded by most samples. The proportion of soil samples collected that exceed this limit can be used to decide whether cleanup is necessary or if a cleanup operation has been successful. The basic idea is to specify (1) an activity level, L, for soil, (2) a proportion, \( p_1 \), of samples with activities greater than L that is acceptable, i.e. for which cleanup is not required, (3) a proportion, \( p_2 \), of samples with activities greater than L that is not acceptable, i.e. for which cleanup is required, (4) the allowable risk, \( \alpha \), of wrongly concluding that cleanup is necessary, and (5) the risk, \( \beta \), of wrongly concluding that cleanup...
is not necessary. Once these quantities have been specified it is possible to determine (1) the number of samples, n, required in order to meet the α and β specifications, and (2) a rejection number, r, such that cleanup is required if r or more of the n samples have activities greater than L. This approach assumes a willingness to tolerate a certain proportion, p₁, of samples with activities greater than L without cleaning up the area. Of course, p₁ can be specified to be as close to zero as we please.

The risk, β, would, presumably, be specified near zero since the consequences of not cleaning up a contaminated area might result in undue risk to the inhabitants of the area. The "power" of the design is 1-β, i.e. 1-β is the probability that the area is cleaned up when it should be cleaned up (when the proportion of soil in the area with activities greater than L is p₂). The number of samples, n, and the rejection number, r, can be determined for given values of p₁, p₂, α, and β using tables prepared by Burstein (1971).

The above approach is known as "acceptance sampling by attributes" the elements of which are discussed elsewhere, e.g., Freeman et al, (1948) and Burr (1976).

We note that attribute sampling is ordinarily used in situations where the "attribute" can be measured accurately for each element examined and decisions about a given population (often a quantity of manufactured product) are to be made on the basis of the sampled elements. Hence we are neglecting "counter error" here and assuming decisions are to be made on the basis of whether or not sample elements from a given area (e.g., soil aliquots) indicate that a proportion of such elements are above some set limit.
Turning now to acceptance sampling by measurements, the cleanup decision is based on average soil concentrations rather than on the proportion of samples with concentrations exceeding $L$. Using the average approach, it is necessary to specify both an acceptable and unacceptable average soil concentration denoted by $\mu_1$ and $\mu_2$, respectively, as well as the $\alpha$ and $\beta$ risks defined above. It is also necessary to specify a value for the anticipated standard deviation ($\sigma$) of the concentration values. This average concentration approach requires that the sample mean, $\bar{x}$, be normally distributed, which may be approximately true even if the individual sample concentrations are skewed (commonly the case in transuranic studies). Nevertheless, it may be preferable to transform the data to logarithms so that the test is made on the basis of the average logarithm of concentrations. This approach requires that $\mu_1$, $\mu_2$, $\sigma$, $\alpha$, and $\beta$ also be in log units. Once $\mu_1$, $\mu_2$, $\sigma$, $\alpha$, and $\beta$ are specified it is relatively simple to determine the number of samples, $n$, to collect and the critical value, $K$ (Burr, 1976, pp. 325-328). Letting $\bar{x}$ be the average concentration of the $n$ collected soil samples, the decision is made to clean up the sampled area if $\bar{x} \geq K$. No cleanup action is taken if $\bar{x} < K$. See Burr (pp. 332-336) for the usual case when $\sigma$ is unknown.

The choice between the attribute and average concentration approach to deciding the cleanup question hinges on the normality assumption. Quoting from Burr (1976, p. 324), "Unless we can build up evidence on the distribution of measurements, we had better stay with the method of attributes." However, the attribute approach may call for substantial numbers of samples (Burr, 1976, p. 347). If the average concentration approach is used and if
transuranic concentrations in adjacent soil samples are not independent, then a useful estimate of the average concentration \( \bar{x} \) might be obtained using an estimation procedure called Kriging (Davis, 1973, pp. 381-390; Delfiner and Delhomme, 1975). Kriging makes use of the correlation structure (if it exists) to obtain an optimum weighted average. We are presently engaged in research to determine the kinds of correlation structures that might exist for transuranics in soil. A disadvantage of the attribute approach is that the additional information available concerning a correlation structure is not used in the decision-making process.

Sampling for cleanup would most likely be done in a sequential manner in order to keep costs to a minimum. The basic idea would be to take a limited number of samples and make a decision whether to cleanup or to withhold judgment until more samples are collected. The general approach as it is applied in industry is discussed by Burr (1976, Chapter 12). The use of acceptance sampling using either attributes or average concentrations requires that samples be collected at random within relatively homogeneous areas. The procedure outlined above should thus be applied separately within each such area. The assumption of random sampling within areas is important in order to preserve the chosen \( \alpha \) and \( \beta \) risks. Consequently, the use of alternative sampling plans such as sampling on a systematic grid would need to be carefully evaluated before being used in a field study.

Once the initial cleanup operation has been completed, additional samples will be required to assure that cleanup to the level desired has
been accomplished. The design of this phase of the sampling program can also be based on acceptance sampling although the details may change from those described above. If a final demonstration (certification) is required and the attribute approach is adopted, then Table 12 in Burstein (1971) can be used to determine the number of samples required to be 100(1-\(\beta\))% sure that the true proportion of samples with concentrations greater than the cleanup level, \(L\), is less than \(p_2\). This approach is based on the assumption that the cleanup operation has been successful so that all samples will have concentrations less than \(L\). Sampling to insure that cleanup criteria have been met should also be done independently for homogeneous areas.

The design of a cleanup sampling plan may involve a combination of in-situ measurements and Pu concentrations in soil samples. If so, these two measurement systems must be well calibrated so that their results can be related. The double sampling approach investigated by Gilbert and Eberhardt (1976) at NTS safety-shot sites offers an approach to estimate the optimum allocation of effort between the in-situ measurements and soil samples.
SAMPLING DESIGN GUIDELINES

Based on our experience in helping design some of the NAEG soil and vegetation studies at safety-shot sites, we would like to suggest several guidelines relative to the design and statistical analysis of environmental radionuclide studies. These guidelines are directed towards estimating the total amount and spatial distribution of transuranics, but the design principles are also applicable to ecosystem-type studies.

**Guideline 1: Break study area into homogeneous subareas.** On the basis of field surveys, information from similar studies, topography of the land, vegetation patterns, or any other relevant information, attempt to divide the total study area into subregions (commonly termed "blocks" or "strata") such that the variability in radionuclide concentrations within subregions is less than that expected for the entire study site. If this stratification is successful, the end result should be a more precise estimate of inventory for the whole site. In addition, of course, estimates of inventory will be obtained for each stratum separately, which are useful for relating trends in soil concentrations with concentrations in other ecosystem components.

The success achieved in increasing the precision of the inventory estimate for the entire study site depends on how effective the stratification has been in dividing the area into relatively homogeneous blocks or strata (Gilbert et al, 1975). An inappropriate choice of strata will yield little if any benefit in increased precision. It has been our experience that it may not be possible to construct a satisfactory stratification plan.
without conducting field surveys and/or collecting samples prior to the main study. This leads us to the next guideline.

**Guideline 2: Consider pilot studies.** If relevant information on the variability and spatial pattern of the radionuclide is not available, a pilot study may yield information that will aid in the design of the main study. It will, hopefully, give indications of trends and levels of variability necessary for defining strata. The kind of information obtained in the pilot study should be appropriate for estimating the number of samples needed in each of the strata to achieve the maximum possible increase in precision of the estimate of inventory or to achieve a specified precision needed to meet the objectives of the study. For example, FIDLER survey readings for $^{241}$Am would not in themselves be adequate for estimating the variability of $^{241}$Am concentrations in 10-gram aliquots of surface soil. A FIDLER survey in conjunction with soil samples collected at a number of FIDLER locations would, in general, be a better approach. Then it might be possible to relate the variability and level of FIDLER readings to those for soil sample concentrations in order to approximate the optimum number of samples for each strata. Of course, the total funds available for the study put an upper limit on the total number of samples that can be collected and analyzed. The number of samples allocated to the various strata could also involve costs of collecting samples if this cost varies substantially between strata. Gilbert et al, (1976a) discuss how the allocation was accomplished for the Area 13 (Project 57) safety-test site on NTS.
Guideline 3: Use random sampling within strata or random sampling in conjunction with systematic sampling. Careful consideration needs to be given to the method used to determine the actual sampling locations. Statisticians tend on theoretical grounds to favor random over systematic sampling. The theory of statistics that permits the formulation of probability statements and inferences about the universe from which sample data are taken is based on the notion of drawing samples at random. However, the greater ease with which systematic samples on a grid, say, can be collected under field conditions, and the need in many cases to insure that all portions of the study site are sampled are reasons for considering systematic sampling.

Gilbert et al. (1975) and Gilbert (1976) found that the use of random sampling within strata tended to leave gaps in the pattern of sample location points which contributed to biases observed in estimated Pu contours obtained using computer algorithms. This problem might have been reduced had a systematic (grid) sampling plan been used within each stratum to insure more uniform coverage. The grid spacing could have varied between strata in accordance with the allocation of samples obtained using the ideas discussed above under Guideline 2.

An alternative sampling plan for these safety-test sites would make use of both systematic and random sampling. One approach would be to grid off each stratum (different grid sizes being allowed for the various strata) and to choose two or more samples at random within each grid square. The grid size could be chosen to insure that the maximum possible distance between samples is acceptably short, while the number of samples within each grid
square could be chosen on the basis of the variability expected between samples. This approach attempts to use the best features of both systematic and random sampling.
The design of a transuranic field study must take into account site-specific characteristics of the contamination such as deposition patterns and the quantity, kind, and properties of the transuranics present. However, general design guidelines can be formulated to aid in the design of these studies. Principal planning steps include (1) a clear statement of objectives, (2) appropriate definition of that part of the environment about which information is desired (the "target population") and that part from which samples are actually taken and to which inferences apply (the "sampled population"), (3) determining the kinds of data and the degree of precision required to meet study objectives, (4) appropriate choice of measurement instrumentation and laboratory procedures, (5) division of the sampled population into sampling units, and (6) design or selection procedure used to select sampling units for analysis.

The design of studies at sites contaminated by local sources of contamination may include surveys using ground or aerial in-situ radiation detection devices. These can help define the spatial pattern of contamination and, in some situations, be used in conjunction with wet chemistry analysis of soil samples to estimate total amounts or average concentrations using double sampling. Stratified random sampling has been shown to be an efficient design for totals or averages at safety-shot sites. Selecting soil samples from undisturbed locations is an acceptable procedure when estimating total accumulated deposition from world-wide fallout or from local sources such as stack emissions where the size of Pu particles is in the micron
range. However, undisturbed sites are, in general, not appropriate at safety-shot or nuclear detonation sites where patterns of deposition may be complex and/or when interest centers on determining the present deposition pattern.

Acceptance sampling by attributes or measurements are two possible approaches for deciding whether cleanup of an area is necessary. When using the attribute approach the decision is made on the basis of the proportion of sample concentrations exceeding some present level. No assumption of normality is needed but the number of samples required may be greater than when using the measurement approach. The measurement approach uses average concentrations to make a decision and depends on the assumption of normality for its validity. Sequential sampling plans seem to offer the most promise for cleanup studies. Three general guidelines are suggested relative to the design of transuranic field studies: (1) divide the study area into homogeneous subareas (strata) if possible, (2) conduct pilot studies if necessary to obtain data for planning the main sampling effort, and (3) within each stratum use random, systematic or some combination of random and systematic sampling unless study objectives specifically require that only "undisturbed" locations are appropriate.

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