SAMPLING INSPECTION AND SURVEY INTERPRETATION: A COMPARISON OF METHODS

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ABSTRACT

Following cleanup of a radioactively contaminated facility or site, surveys must be performed to demonstrate compliance with regulatory release limits and guidelines. Surveys produce measured estimates of residual radioactivity at selected locations. Rarely can these locations provide complete 100% coverage of an entire affected area, and the effectiveness of the survey as a basis for judging the acceptability of an area can be improved, over the comparison of results with limits, by the use of statistical interpretation. This approach uses the methods of sampling inspection. Two methods of survey interpretation will be compared. One method is based on an extension of sampling inspection by variables, as currently presented in ANSI/ASQC Z1.9-1980, and has been used in several decommissioning projects under both NRC and DOE jurisdiction. The other method is that presented in NUREG/CR-5849, which draws on EPA approaches to confirming the acceptability of an area. These methods will be explored in terms of measurement techniques, effort required, statistical basis, and interpretation. Specific examples will be shown.

INTRODUCTION

The purpose of a final status survey, performed as the last step in a decontamination or remediation project, is to provide a demonstration that the remediation effort has been adequately effective and that the site is in compliance with the appropriate guidelines and regulatory limits. To emphasize, the final status survey is done to demonstrate compliance, rather than to determine <u>if</u> the site is in compliance. To do this, the results of the survey must provide clear and direct information supporting the conclusion that compliance has been demonstrated. The foundation for this judgment must be based on appropriate measurements made in suitable locations. The survey results must be interpreted in an understandable fashion because the meaning contained within a table of survey results is often hidden from the reader.

The draft document, NUREG/CR-5849 (1), describes one approach to building this foundation, drawn from the experience of the ORISE staff in performing confirmatory surveys. During many decommissioning projects at Rockwell International, we have developed a somewhat different approach, using similar tools and techniques. This paper compares these two methods in terms of measurement techniques, effort required, statistical basis, and interpretation.

Field survey measurements of surface radioactivity are generally made with large area (80 cm^2) alpha scintillator probes, smaller area (20 cm^2) beta thin-window pancake GM probes, and 1x1 inch NaI probes for gamma exposure rate. (The pancake GM probes that are used for "beta" measurements are equally sensitive to alpha activity, but the high background countrate makes them less useful for alpha surveys.) Other detector types, such as large area (100 cm^2) proportional detectors and organic scintillators or High Pressure Ion Chambers (HPIC) for truer measurements of dose or exposure rates, may be more effective both in making the measurements and in providing clearly credible data.

Sampling inspection, with statistical interpretation of the results, is based on the concept that measurement of a condition at a small number of appropriately selected locations will provide adequate information to reach a judgment on that condition for the entire facility.

NRC Guidance

The survey process presented in NUREG/CR-5849 consists of an initial qualitative screening survey of 100% of the affected area at the site, followed by uniformly spaced "point" measurements, based on a 2m x 2m or 1m x 1m grid, depending on the effectiveness of the screening survey. (If the screening survey can detect residual radioactivity below 25% of the guideline, the larger grid may be used.) The screening survey ensures that no significant contamination remains anywhere at the site, to the extent that 100% surveying is achievable. "Hot spots," if any, are identified in this survey for later quantitative determination. The point or inspection measurements produce the data that will be statistically interpreted to show probabilistic compliance with the guidelines.

NUREG/CR-5849 recommends a 100% survey to ensure that the sampling inspection measurements will not miss a problem area. The regulatory agencies are not yet ready to accept a purely probabilistic statement based on measurements of a small fraction of the existing area.

This formal screening survey, performed after all the remediation work has been completed, is more easily accepted by the agencies than is a concurrent survey, performed during the course of decontamination, but it requires additional effort that does not produce a cleaner facility.

The procedure for making sampling inspection measurements for surface radioactivity that is described in NUREG/CR-5849 provides for establishing a 2m x 2m grid (or 1m x 1m, if the screening survey is not sensitive at less than 25% of the guideline) and making a single-point measurement, with the probe stationary, for a count time of 1 minute, using a scaler to produce numerical results for statistical interpretation. This will result in sampling approximately 0.05 to 0.2% of the surface area if a pancake probe is used or about 0.2 to 0.8% if a large area alpha scintillator is used. These locations uniformly cover the surface being inspected.

Rockwell Practice

In Rockwell practice, the screening survey is done in conjunction with the remediation operation, by hunting for and identifying areas that require cleaning or removal. (Usually, after decontamination, such areas are the cleanest, most free of residual radioactivity, in the facility because their freedom from contamination is specifically confirmed during the decontamination work.) Sometimes, as work progresses, this survey must be repeated because of re-contamination during the cleanup or because the reduction in ambient radiation permits more sensitive surveying. We have learned that, as if to compensate for the qualitative nature of this part of the survey, the survey technique should differ from those used in the inspection measurements. For example, high exposure-rate areas are found much more effectively by traversing the gamma-probe at the surface, rather than at 1 meter, as provided in the statement of the exposure-rate limit.

In performing final surveys of decontaminated facilities, we establish an overall 3m x 3m grid to ensure uniform coverage of the surface area by the sampling inspection measurements. A qualitative scan of each 3m x 3m master grid is performed, in a manner similar to the qualitative scan recommended in NUREG/CR-5849 for each 1m x 1m area. Based on the qualitative scan or other indications, a 1m x 1m location is selected for the inspection measurement. Selection of one location from each set of nine permits biasing the inspection sample towards the more likely locations of residual contamination. This selection results in 11% of the surface area being tested. A smaller number of measurements are made in the Rockwell survey than in that described by NUREG/CR-5849, by a factor of 2.25 to 9, yet the area covered by the Rockwell inspection measurements is 14 to 220 times the corresponding measurement area of the NUREG/CR-5849 survey.

For sampling inspection measurements of surface radioactivity, Rockwell has taken a very literal interpretation of the guideline statement, "less than (a specified number of) dpm/100 cm^2 averaged over 1 square meter," and specifically measures the average surface radioactivity of each selected 1-square-meter area. This is done by slowly moving the probe over a 1m x 1m square, for a 5-minute scan time. (If both alpha and beta contamination are possible, an alpha scintillator and a pancake GM are mounted together as a single unit and two separate scalers are used. Thus, both measurements are done simultaneously.) The surveyor must watch, or listen, for hot spots during this scan, and then investigate any found to determine compliance with the maximum contamination limit. In our experience, hot spots are very rare. In addition to the total surface radioactivity measurement, a single smear swipe of 100 cm^2 is made in this 1 m^2, to measure the removable contamination.

STATISTICAL INTERPRETATION

There are several different approaches for developing the statistical interpretation and establishing the criteria for accepting or rejecting an area for compliance. NUREG/CR-5849 has adopted the EPA approach, which is based on ensuring that the true mean residual contamination in an area, as estimated by the measurements, is below the allowable limit. This approach is well established in EPA practices for hazardous materials, as described in SW-486, "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods" (2). This leads to the following mathematical criterion for acceptance:

$$\bar{x} + t[s/\sqrt{n}] < c_G$$

where

- $\bar{x}$ is the arithmetic mean of the survey results,
- t is "Student's" t for 95% confidence and for the number of degrees of freedom of the sample (number of measurements less one),
- s is the standard deviation calculated for the sample measurements,
- n is the number of measurements tested,

and C_G is the allowable limit.

The Rockwell approach is based on guidance developed by the State of California Radiologic Health Branch for its inspectors and is derived from standard sampling inspection procedures. California, in DECON-1 (2), requires a "consumer's risk" of 10% for a "Lot Tolerance Percent Defective" (LTPD) of 10%, based on inspection per 100 ft^2. For hot spots, DECON-1 applies an accept/reject test derived from sampling inspection by attributes, that is, whether a hot spot exceeds the allowable maximum or not. However, for the average and removable activity measurements, a Gaussian test is applied to the mean and standard error of the mean at the 90% level.

For the acceptance test used by Rockwell, the consumer's risk and LTPD values were used to develop a test according to the methods of sampling inspection by variables. This provides the following mathematical criterion for acceptance:

$$\bar{x} + ks < C_G$$

where k is the tolerance factor, and is a function of the consumer's risk, the LTPD, and n.

$$k = [K_2 + (K_2 2 - ab)^{1/2}]/a$$
$$a = 1 - K_\beta^2/[2(n-1)]$$
$$b = K_2 2 - K_\beta^2/n$$
$$K_\beta = 1.2816 \text{ for consumer's risk} = 10\%$$
$$K_2 = 1.2816 \text{ for LTPD} = 10\%$$

Conceptually, the difference between these tests is that NUREG/CR-5849 tests the average while Rockwell tests the distribution. In the jargon of sampling inspection, the Rockwell test is a "90/90/100" test, indicating that the test provides 90% confidence that 90% of the lot (area) is below 100% of the limit. In this same manner, the NUREG/CR-5849 test is a "95/50/100" test: it provides 95% confidence that 50% of the lot (area) is below 100% of the limit.

An apparent shortcoming of the average test, in principle, is that for a bizarre distribution of contamination, where nearly half the locations were contaminated to nearly twice the allowable limit, this test would be passed if enough locations were measured. (Those locations measured as exceeding the limit would require remediation, but that would not significantly affect the remaining residual radioactivity, as estimated by the inspection test.)

A disadvantage of the distribution test is that it is more likely to reject marginal situations. That is, the distribution test requires more effective, more complete decontamination than does the average test.

This dilemma must be resolved by a policy decision as to "How Clean is Clean?"

EXAMPLES

To illustrate the application of these two different inspection tests, several actual cases have been analyzed. Two cases are taken from NUREG/CR-5849, and two cases are taken from recent projects at Rockwell International's Santa Susana Field Laboratory (SSFL).

Example 1

This case, presented as "Sample Calculation 1" on page 8.10 of NUREG/CR-5849, shows the surface activity measured at 35 systematic locations. The allowable limit is 5000 dpm/100 cm^2 (applicable to uranium and low-hazard beta emitters). No measured value exceeds the limit; three measurements were below the instrument detection limit. The test results are:

limit	5000
mean	2478
standard deviation	1196
number of measurements	35
NUREG/CR-5849	Rockwell
t 1.692	k 1.613
$\bar{x} + t[s/\sqrt{n}] = 2820 < 5000$	$\bar{x} + ks = 4407 < 5000$
pass	pass

In this case, the data pass both tests, although with a noticeably narrower margin in the Rockwell test. As part of the Rockwell analysis, the data values are displayed graphically on a linearized Gaussian cumulative probability plot, the Sampling Inspection Test plot, shown in Fig. 1. (In this type of plot, data from a Gaussian (normal) distribution lie very close to a straight line representing the theoretical distribution. The diagonal line representing the Gaussian intersects the center gridline (50%) on this plot at the mean and the slope of the line is determined by the standard deviation: the line passes through the 84.1% point at 1 standard deviation above the mean.)

In this figure, the so-called test-statistic ($\bar{x}$ + ks) value (4407 dpm/100 cm^2 in this case) is shown, as is the corresponding Gaussian probability required to achieve the assurance that 90% of the tested area is below the allowable limit, with 90% confidence. For increasingly large sample sets, this probability line approaches the 90% probability line.

Visual inspection of the plot shows that the distribution of values is reasonably Gaussian. The three MDA values at the left end show some departure from the ideal, as would be expected.

Example 2

The second case for comparison is "Sample Calculation 2" from page 8.11 of NUREG/CR-5849. This case shows net radioactivity in soil (pCi/g) at 20 random sampling locations. The guideline value adopted is 4 pCi/g. Two values exceed the limit by small amounts, and it is assumed that these have been found to be allowable on the basis of the soil hot-spot rule, or would be remediated. The results of the two tests applied to these data are:

limit	4
mean	2.36
standard deviation	1.12
number of measurements	20
NUREG/CR-5849	Rockwell
t 1.729	k 1.744
$\bar{x} + t[s/\sqrt{n}] = 2.79 < 4$	$\bar{x} + ks = 4.32 > 4$
pass	fail

The corresponding Sampling Inspection Test plot for this data set is shown in Fig. 2. The failure of this data set to pass the Rockwell test is seen from the Gaussian distribution line passing above the limit at the adjusted probability required to achieve 90% confidence. That is, at the 90% confidence level, 10% (or more) of the area exceeds the allowable limit.

Example 3

At Rockwell SSFL, an area with contaminated soil was recently decontaminated, after being partially decontaminated several years earlier. A final status survey was performed by testing gamma exposure rate and Cs-137 concentration. This survey was performed with 1m x 1m square grids, as shown in Fig. 3. The limit on gamma exposure rate was chosen to be 5 μR/hr above natural background at 1 meter from the ground surface. Background was determined to be 15.5 μR/hr from measurements in a nearby similar area. A RESRAD (3) calculation was done to determine the limit for soil radioactivity: assuming an equal activity concentration of Sr-90 with the Cs-137, the limit for uniform, infinitely deep Cs-137 activity is 60.4 pCi/g. After remediation, a RESRAD calculation based on the actual estimated average and thickness showed an expected annual dose of 5.2 mrem/year.

Treating the data as they are, without regard for the recommendation that gamma exposure rate be averaged over 10 m^2 and soil radioactivity be averaged over 100 m^2, the two test methods give the following results:

Gamma Exposure Rate

limit	20.5
mean	17.73
standard deviation	0.89
number of measurements	60
NUREG/CR-5849	Rockwell
t 1.672	k 1.526
$\bar{x} + t[s/\sqrt{n}] = 17.93 < 20.5$	$\bar{x} + ks = 19.09 > 20.5$
pass	pass

Cs-137 Concentration

limit	60.4
mean	4.88
standard deviation	4.49
number of measurements	60
NUREG/CR-584	Rockwell
t 1.672	k 1.526
$x + t[s/\sqrt{n}] = 5.85 < 60.4$	$\bar{x} + ks = 11.73 < 60.4$
pass	pass

Here we see that the two methods produce very similar results for the test statistic for gamma exposure rate, but rather different values for Cs-137 concentration. This is due to the small variability in the exposure rate measurements and the relatively high variability in the Cs-137 measurements. In fact, the exposure rate data come close to failing the Rockwell test, and would have if a slightly lower background value had been used for the test limit. The Cs-137 concentration passes easily in both tests because of the relatively high limit. The Sampling Inspection Test plots produced by the Rockwell tests for these two data sets are shown in Fig. 4 and 5.

In order to make a data set that is consistent with the averaging guidelines presented in NUREG/CR-5849 for gamma exposure rate (10 m^2) and soil radioactivity (100 m^2), suitable groups of 1-m^2 grid data were averaged. Applying the two test methods to these condensed data sets gave the following results:

Gamma Exposure Rate

limit	20.5
mean	17.66
standard deviation	0.56
number of measurements	19

NUREG/CR-5849	Rockwell
t 1.734	k 1.758
$\bar{x} + t[s/\sqrt{n}] = 17.88 < 20.5$	$\bar{x} + ks = 18.65 < 20.5$
pass	pass

Cs-137 Concentration

limit	60.4
mean	4.74
standard deviation	2.52
number of measurements	4

NUREG/CR-5849	Rockwell
t 1.833	k 2.012
$\bar{x} + t[s/\sqrt{n}] = 17.8 < 314$	$\bar{x} + ks = 29.5 < 314$
pass	pass

The Sampling Inspection Test plots for the condensed data sets are shown in Fig. 6 and 7.

Example 4

Another decontamination project at Rockwell SSFL, followed by a final status survey, involved a low area where rainfall runoff collected and evaporated. This area was found to have Cs-137 at about 100 pCi/g, in a layer of soil about 6 to 8 inches thick. After removal of much of this dirt, the area was surveyed for gamma exposure rate and soil samples were analyzed for Cs-137. The layout of a square grid, based on 4-ft squares to fit the size of the site in this case, is shown in Fig. 8. Since this area was so small, the survey results will be interpreted as they are, without averaging, as was done in the previous case.

Results of the two test methods are shown below:

Gamma Exposure Rate

limit	18.1
mean	14.25
standard deviation	0.57
number of measurements	30

NUREG/CR-5849	Rockwell
t 1.701	k 1.644
$\bar{x} + t[s/n] = 14.42 < 18.1$	$\bar{x} + ks = 15.19 < 18.1$
pass	pass

Cs-137 Concentration

limit	314
mean	13.13
standard deviation	8.15
number of measurements	10

NUREG/CR-5849	Rockwell
t 1.833	k 2.012
$\bar{x} + t[s/n] = 17.8 < 314$	$\bar{x} + ks = 29.5 < 314$
pass	pass

In this case, both tests reach the same conclusion, for exposure rate because the variability is so small, and for Cs-137 concentration because the limit is so high. The Sampling Inspection Test plots for these data sets are shown in Fig. 9 and 10.

SUMMARY AND CONCLUSIONS

In final surveys, average 1-m^2 measurements of total surface radioactivity may be preferable to multiple point measurements because of the greater quantity of information obtained with reduced data processing. This measurement method also provides a more direct measure of the condition being tested.

Statistical interpretation of final status survey data can improve the effectiveness and objectivity of the survey in reaching a conclusion that the site is clean. Consideration should be given as to whether the acceptance test should address the average condition of the site or the distribution of possible residual contamination levels. It is because of this consideration of the tail of the distribution that the Rockwell method always provides a higher (more conservative) test statistic than the NUREG/CR-5849 method. Choice of such a more rigorous test in the interpretation of a final survey provides greater likelihood that a subsequent confirmatory survey by the regulatory agency will concur that the site is suitable for unrestricted release.

REFERENCES

1. J. D. BERGER, "Manual for Conducting Radiological Surveys in Support of License Termination, Draft Report for Comment," NUREG/CR-5849, U.S. Nuclear Regulatory Commission (1992).
2. USEPA, "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods," SW-486, Third Edition, U.S. Environmental Protection Agency (November 1986).
3. "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use," DECON-1, State of California Department of Health Services, Radiologic Health Branch (June 1977).
4. T. L. GILBERT, C. YU, Y. C. YUAN, A. J. ZIELEN, M. J. JUSKO, and A. WALLO III, "A Manual for Implementing Residual Radioactive Material Guidelines", ANL/ES-160:DOE/CH/8901, Argonne National Laboratory (June 1989).

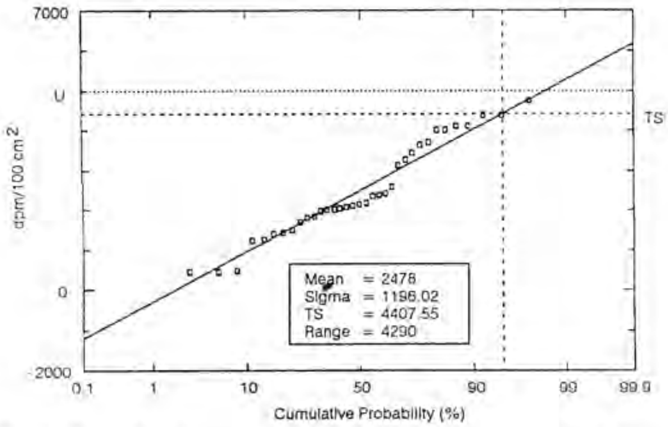

Fig. 1. Sampling inspection test plot of surface survey data from NUREG/CR-5849, "Sample Calculation 1."

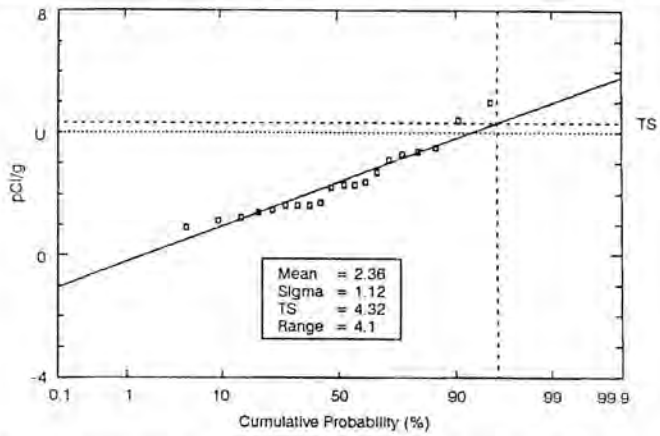

Fig. 2. Sampling inspection test plot for soil radioactivity data from NUREG/CR-5849, "Sample Calculation 2."

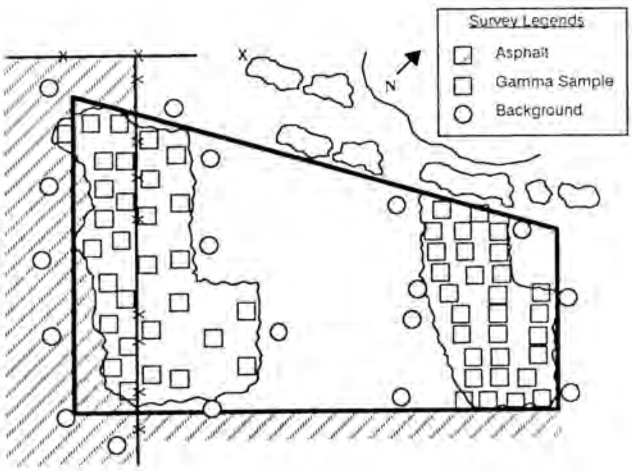

Fig. 3. Remediation excavations and survey and soil sample locations for Rockwell SSFL Case 1.

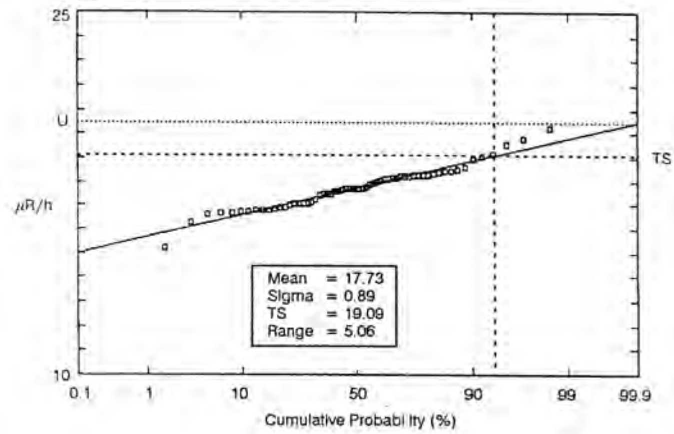

Fig. 4. Sampling inspection test plot of exposure-rate results for Rockwell SSFL Case 1. (Suppressed zero to emphasize variations.)

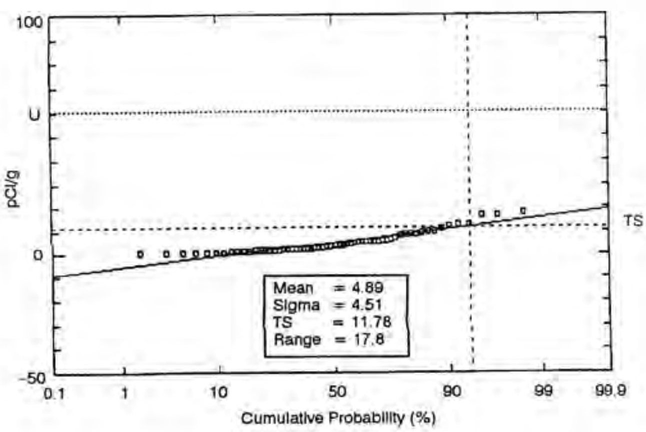

Fig. 5. Sampling inspection test plot of Cs-137 soil activity measured by soil sampling for Rockwell SSFL Case 1.

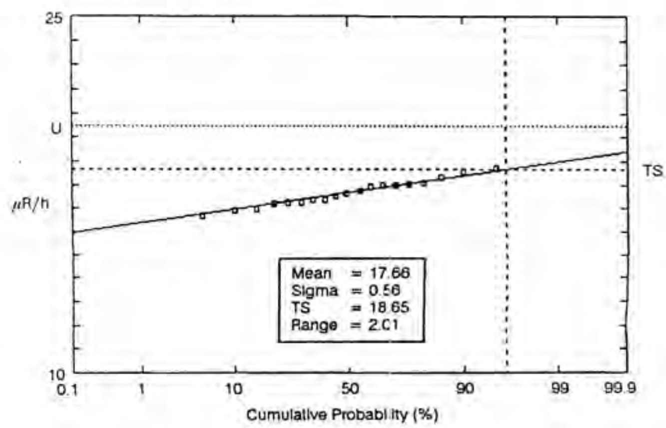

Fig. 6. Sampling inspection test plot of condensed set of exposure-rate readings for Rockwell SSFL Case 1.

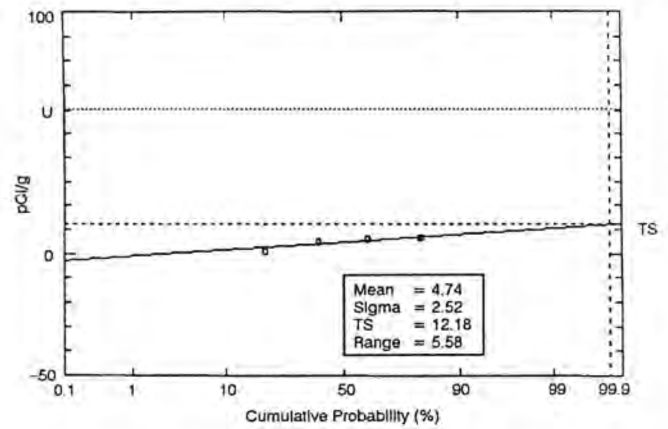

Fig. 7. Sampling inspection test plot of condensed set of Cs-137 soil activity for Rockwell SSFL Case 1.

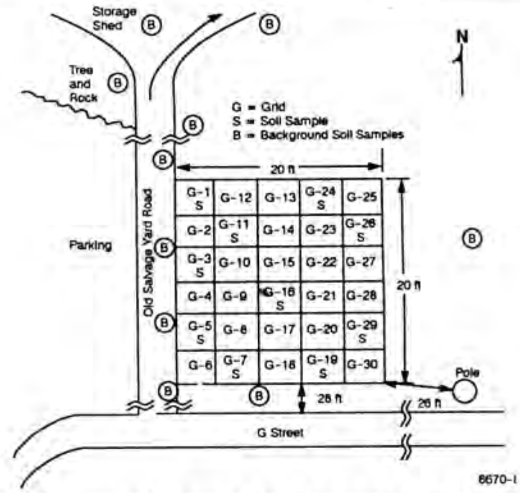

Fig. 8. Survey grid layout for Rockwell SSFL Case 2.

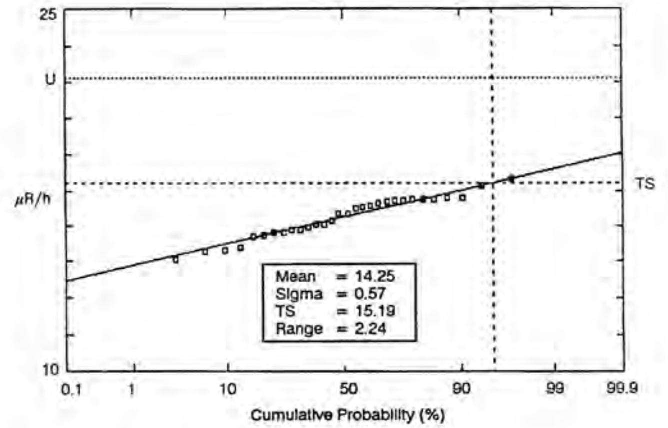

Fig. 9. Sampling inspection test plot of exposure-rate readings for Rockwell Case 2.

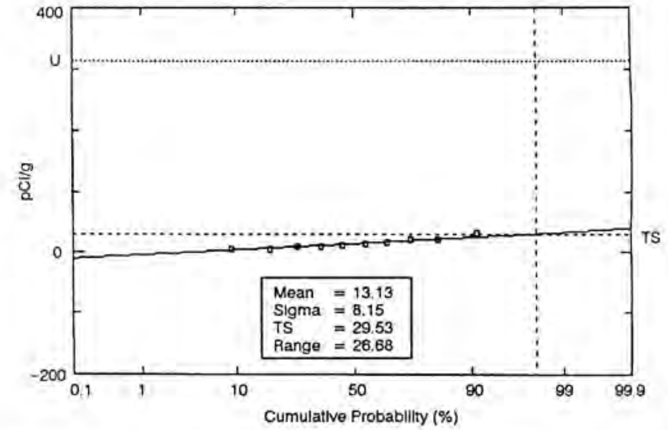

Fig. 10. Sampling inspection test plot of Cs-137 soil activity measured by soil sampling for Rockwell SSFL Case 2.