APPENDIX A
Example of MARSSIM Applied to a Final Status Survey

A.1 Introduction

This appendix presents the final status survey for a relatively simple example of a radiation site. Portions of this example appear earlier in Chapter 5 and Chapter 8. This appendix highlights the major steps for implementing a final status survey and gathering information needed to prepare a report. The report's format will vary with the requirements of the responsible regulatory agency. The Final Status Survey Checklist given at the end of Section 5.5 serves as a general outline for this appendix—although not every point is discussed in detail. Chapters providing discussions on particular points are referenced at each step. This example presents detailed calculations for a single Class 1 survey unit. Section A.2 addresses the completion of steps 1-4 of the Data Quality Objectives (DQO) Process (see Appendix D, Sections D.1 to D.4). Section A.3 addresses the completion of steps 5-7 of the DQO Process (see Appendix D, Sections D.5 to D.7). Section A.4 covers survey performance. Section A.5 discusses evaluating the survey results using Data Quality Assessment (DQA, see Appendix E).

A.2 Survey Preparations

(Chapter 3- Historical Site Assessment)

The Specialty Source Manufacturing Company produced low-activity encapsulated sources of radioactive material for use in classroom educational projects, instrument calibration, and consumer products. The manufacturing process—conducted between 1978 and 1993—involved combining a liquid containing a known quantity of the radioactive material with a plastic binder. This mixture was poured into a metal form and allowed to solidify. After drying, the form and plastic were encapsulated in a metal holder which was pressure sealed. A variety of radionuclides were used in this operation, but the only one having a half-life greater than 60 days was ^{60}Co. Licensed activities were terminated as of April 1993 and stock materials containing residual radioactivity were disposed using authorized procedures. Decontamination activities included the initial identification and removal of contaminated equipment and facilities. The site was then surveyed to demonstrate that the radiological conditions satisfy regulatory agency criteria for release.

A.2.1 Identify the Radionuclides of Concern

(Section 4.3)

More than 15 half-lives have passed for the materials with a half-life of 60 days or less. Based on radioactive decay and the initial quantities of the radionuclides, the quantities that could remain at the site are negligible. A characterization survey confirmed that no radioactive contaminants, other than ^{60}Co, were present.

A.2.2 Determine Residual Radioactivity Limits (DCGLs)
(Section 4.3)

The objective of this survey is to demonstrate that residual contamination in excess of the release criterion is not present at the site. The $DCGL_W$ for ^{60}Co used for evaluating survey results is 8,300 Bq/m^2 (5,000 dpm/100 cm^2) for surface contamination of structures. The $DCGL_W$ for contamination in soil is 140 Bq/kg (3.8 pCi/g).[1]

A.2.3 Classify Areas Based on Contamination Potential.
(Section 4.4)

This facility consists of one administration/manufacturing building situated on approximately 0.4 hectares (1.0 acres) of land as shown in Figure A.1. The building is a concrete block structure on a poured concrete slab with a poured concrete ceiling. The northern portion of the building housed the manufacturing operations, and consists of a high-bay area of approximately 20 m x 20 m with a 7 m high ceiling. The remainder of the building is single-story with numerous small rooms partitioned by drywall construction. This portion of the building, used for administration activities, occupies an area of approximately 600 m^2 (20 m x 30 m). The license does not authorize use of radioactive materials in this area. Operating records and previous radiological surveys do not identify a potential for residual contamination in this section of the building. Figure A.2 is a drawing of the building.

The property is surrounded by a chain-link security fence. At the northern end of the property, the surface is paved and was used as a parking lot for employees and for truck access to the manufacturing and shipping/receiving areas. The remainder of the property is grass-covered. There are no indications of incidents or occurrences leading to radioactive material releases from the building. Previous surveys were reviewed and the results were determined to be appropriate for planning the final status survey. These surveys identified no radioactive contamination outside the building.

A.2.4 Identify Survey Units
(Section 4.6)

Based on the results of other decommissioning surveys at the site and the operating history, the following survey units were used to design the final status survey. All of the interior survey units consist of concrete surfaces (either poured concrete or cinder block) with the exception of the administration areas which are drywall. The results of previous surveys demonstrated that the same reference area could be used to represent the poured concrete and cinder block surfaces.

---

[1] The DCGL values used in this appendix are meant to be illustrative examples and are not meant to be generally applied.

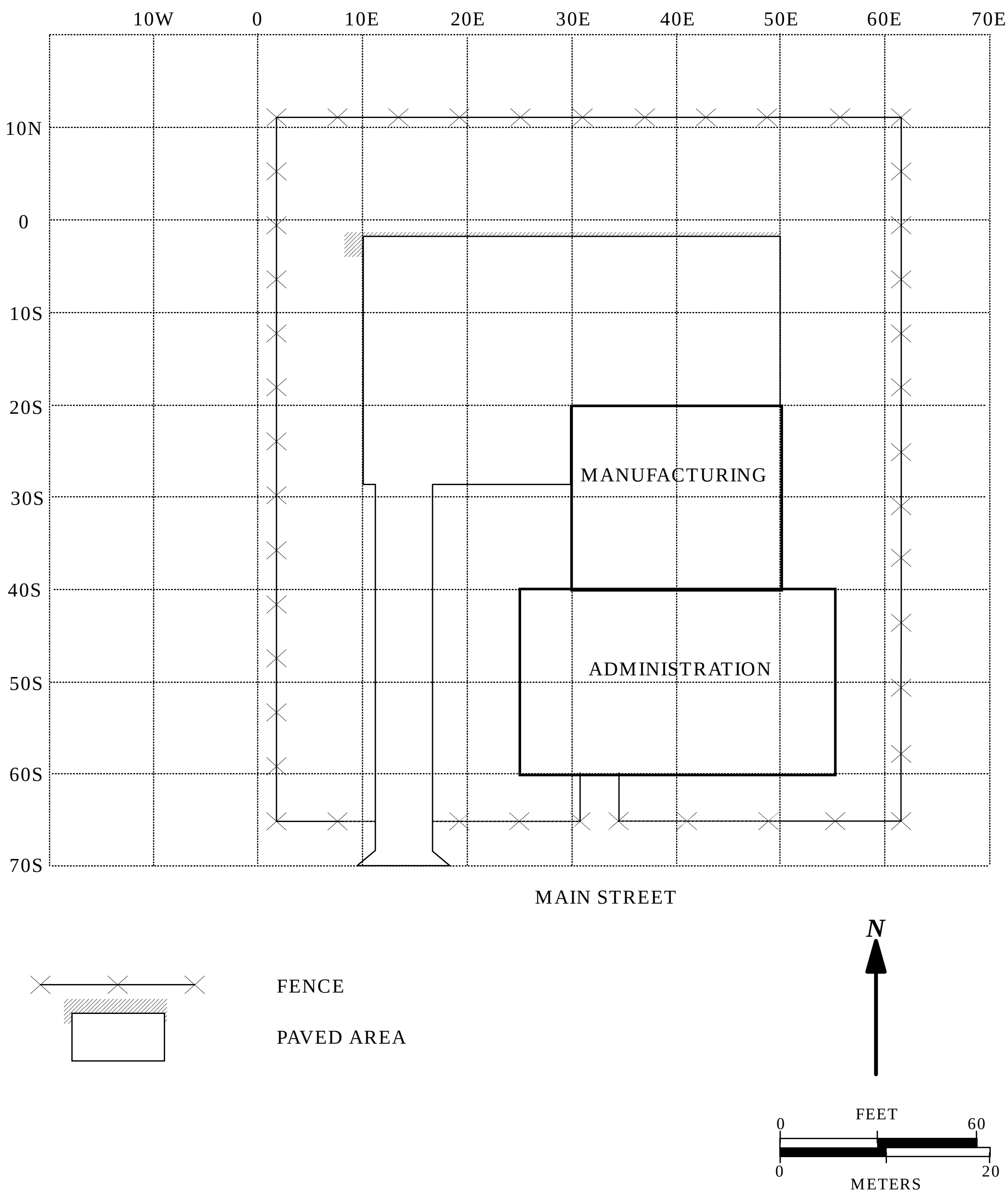


Figure A.1 Plot Plan of the Specialty Source Manufacturing Company

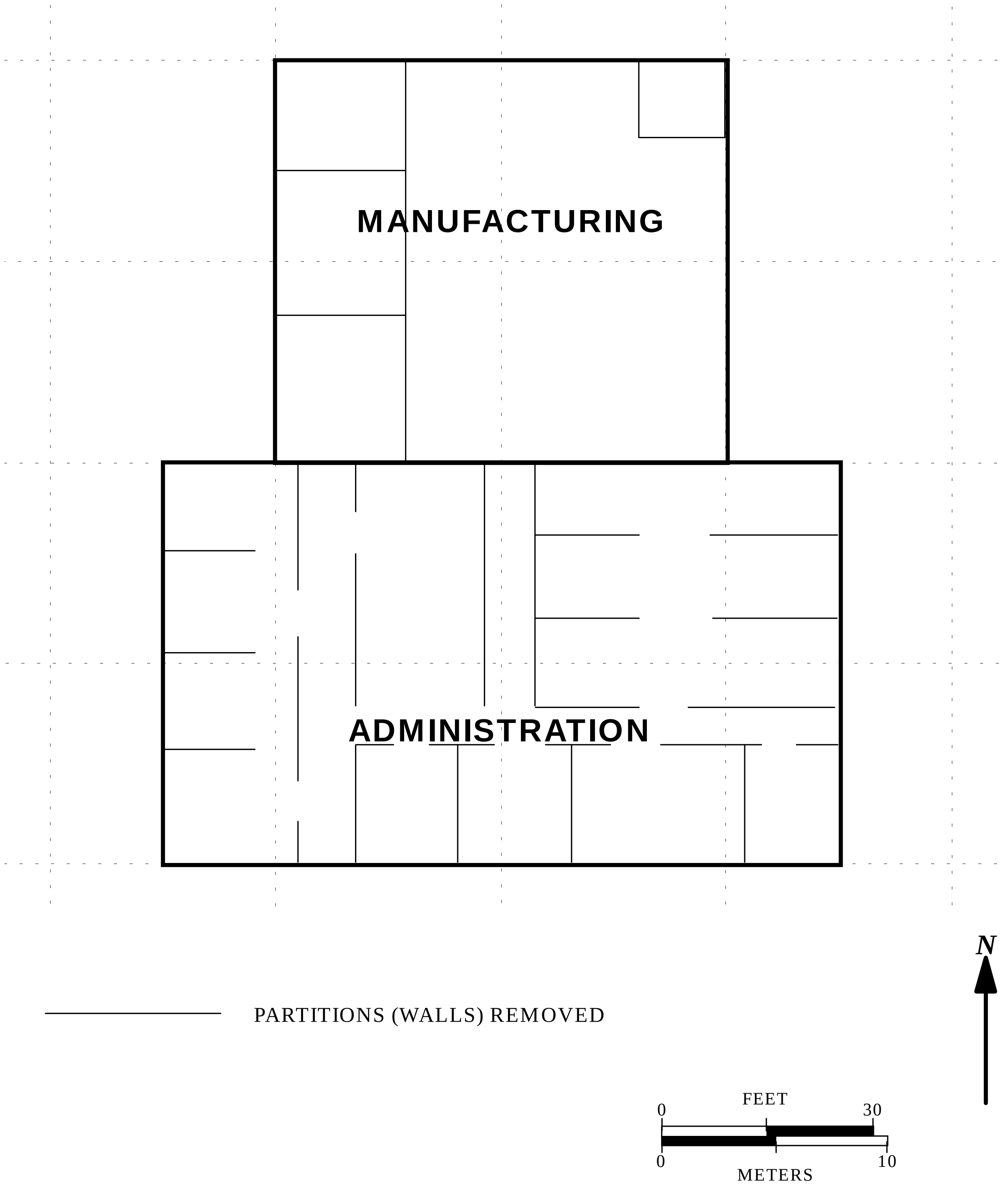


Figure A.2 Building Floor Plan

Structures

Class 1	Floor and lower walls (up to 2 meters above the floor) of manufacturing area - 4 survey units of 140 m^2 each.
Class 2	Upper walls (over 2 meters above the floor) of manufacturing area - 4 survey units of 100 m^2 each. Ceiling of manufacturing area - 4 survey units of 100 m^2 each. Paved area outside manufacturing area roll-up door - 1 survey unit of 60 m^2.
Class 3	Floors and lower walls of administration areas - 1 survey unit. Remainder of paved surfaces - 1 survey unit.

Land Areas

Class 3	Lawn areas - 1 survey unit.

A.2.5 Select Survey Instrumentation and Survey Techniques

(Section 4.7, Chapter 6, Chapter 7, Appendix H, and Appendix M)

For interior surfaces, direct measurements of gross beta activity were made using one minute counts on a gas flow proportional counter with an MDC of 710 Bq/m^2 (425 dpm/100 cm^2). This is actually less than 10% of the DCGL for ^{60}Co. Surfaces were scanned using either a 573 cm^2 floor monitor with an MDC of 6,000 Bq/m^2 (3,600 dpm/100 cm^2) or a 126 cm^2 gas flow proportional counter with an MDC of 3,300 Bq/m^2 (2,000 dpm/100 cm^2).

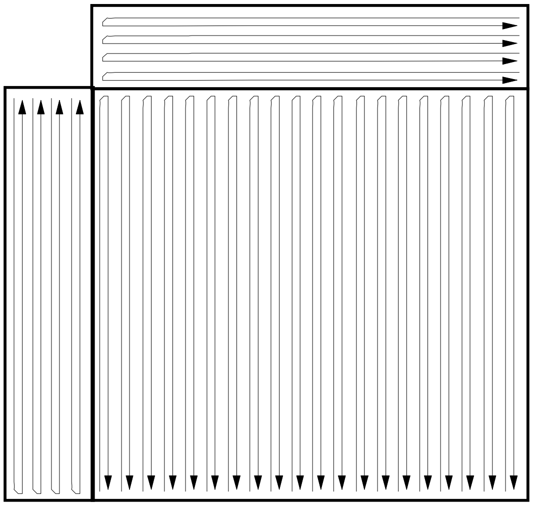
Exterior soil surfaces were sampled and counted in a laboratory using a Ge spectrometer with an MDC of 20 Bq/kg (0.5 pCi/g). This is actually slightly greater than 10% of the DCGL for ^{60}Co. Soil surfaces were scanned using a NaI(Tl) scintillator with an MDC of 185 Bq/kg (5.0 pCi/g) of ^{60}Co.

Examples of scanning patterns used in each of the Class 1, 2, and 3 areas are shown in Figure A.3.

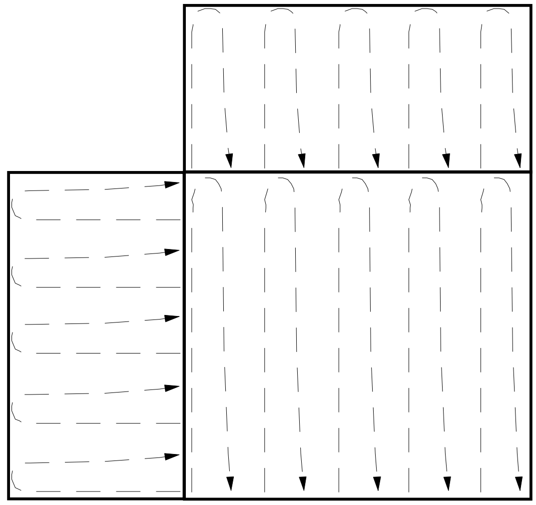
A.2.6 Select Representative Reference (Background) Areas

(Section 4.5)

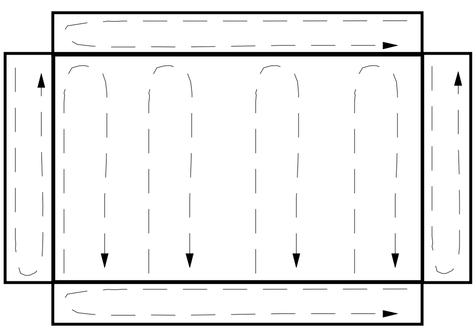
For the purposes of evaluating gross beta activity on structure surfaces, a building of similar construction was identified on the property immediately east of the site. This building served as a reference for surface activity measurements. Two reference areas—one for concrete surfaces and one for drywall surfaces—were required. Because ^{60}Co is not a constituent of background and evaluation of the soil concentrations was radionuclide-specific, a reference area was not needed for the land area surveys.



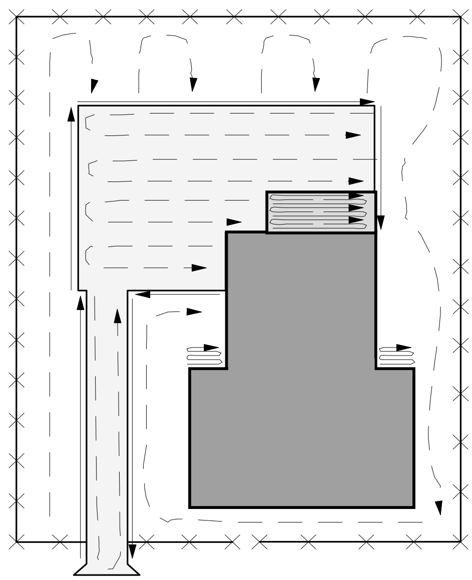
Interior Concrete Survey Units
Class 1 Floors - 100% Scan with Floor Monitor
Class 1 Walls - 100% Scans with Gas Flow Proportional Counter



Manufacturing Area Upper Walls and Ceiling
Class 2 Areas - 25% Scans with Gas Flow Proportional Counter



Administration/Office Areas
Class 3 Floors - 25% Scan with Floor Monitor
Class 3 Walls - 25% Scan with Gas Flow Proportional Counter



Class 2 Paved Area - 100% Scan with Floor Monitor
Class 3 Paved Area - 25% Scan with NaI(Tl)
Class 3 Lawn Area - 100% Scan with NaI(Tl) at Downspouts and Edge of Pavement (Runoff Areas)
10% Scan with NaI(Tl) on Remaining Lawn Area

Figure A.3 Examples of Scanning Patterns for Each Survey Unit Classification

A.2.7 Prepare Area
(Section 4.8)

Prior to the survey, and as part of the decommissioning process, all internal partitions were removed from the manufacturing area. Other items removed include the radioactive material control exhaust system, a liquid waste collection system, and other furnishings and fixtures not considered an integral part of the structure.

A.2.8 Establish Reference Coordinate Systems
(Section 4.8.5)

Land areas were gridded at 10 m intervals along north-south and east-west axes in preparation for the characterization survey as shown in Figure A.1. The grid was checked to verify its use for the final status survey.

Structure surfaces were already gridded at 2 m intervals, incorporating the floors and the lower 2 m of the walls. Figure A.4 is an example of the coordinate system installed for one of the Class 1 interior concrete survey units.

A.3 Survey Design

A.3.1 Quantify DQOs
(Section 2.3, Appendix D)

The null hypothesis for each survey unit is that the residual radioactivity concentrations exceed the release criterion (Scenario A, Figure D.5). Acceptable decision error probabilities for testing the hypothesis were determined to be α=0.05 and β=0.05 for the Class 1 interior concrete survey units, and α=0.025 and β=0.05 for all other survey units.

A.3.2 Construct the Desired Power Curve
(Section 2.3, Appendix D.6, Appendix I.9)

The desired power curve for the Class 1 interior concrete survey units is shown in Figure A.5. The gray region extends from 4,200 to 8,300 Bq/m^2 (2,500 to 5,000 dpm/100 cm^2). The survey was designed for the statistical test to have 95% power to decide that a survey unit containing less than 4,200 Bq/m^2 (2,500 dpm/100 cm^2) above background meets the release criterion. For the same test, a survey unit containing over 17,000 Bq/m^2 (10,000 dpm/100 cm^2) above background had less than a 2.5% probability of being released.

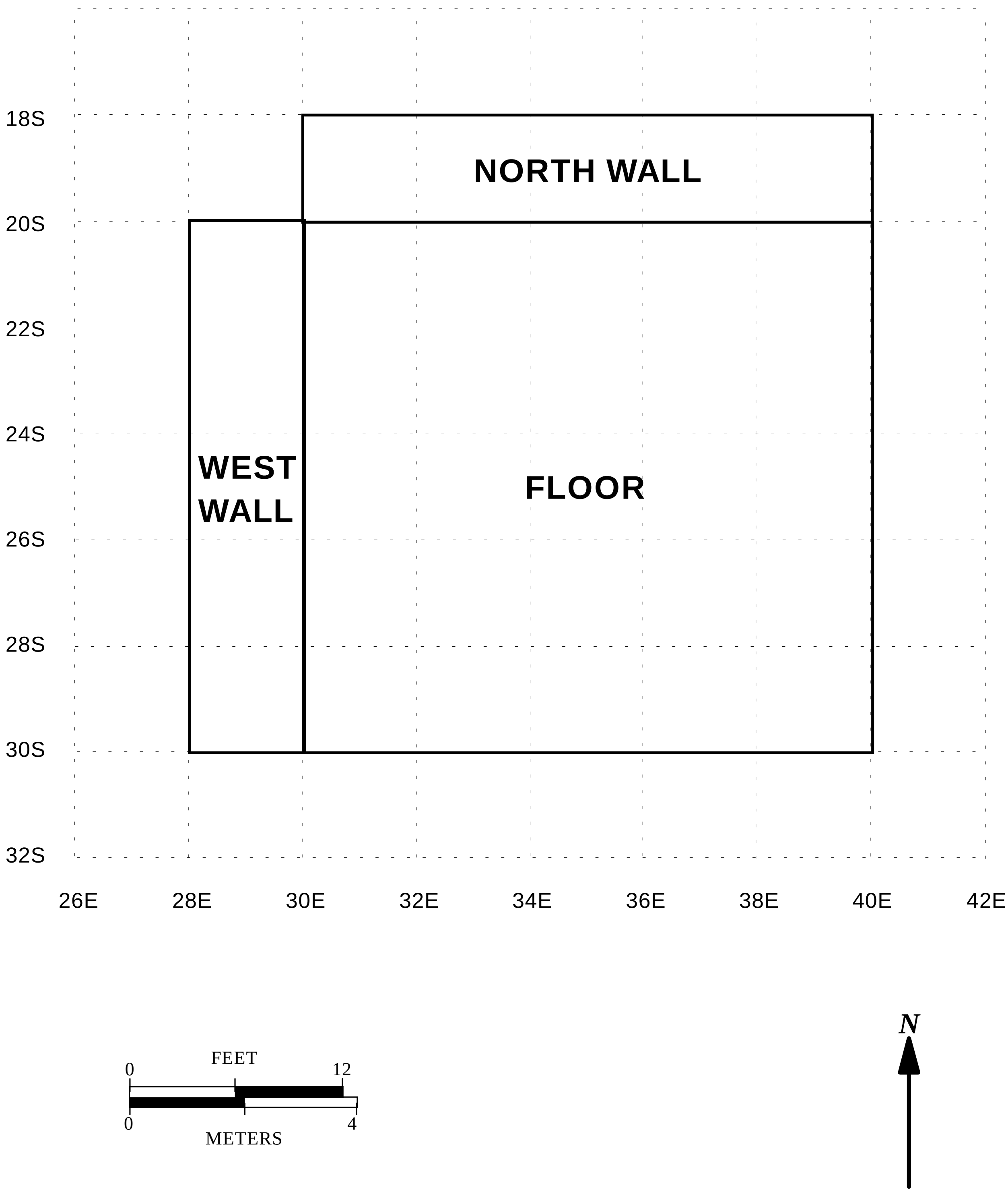


Figure A.4 Reference Coordinate System for the Class 1 Interior Concrete Survey Unit

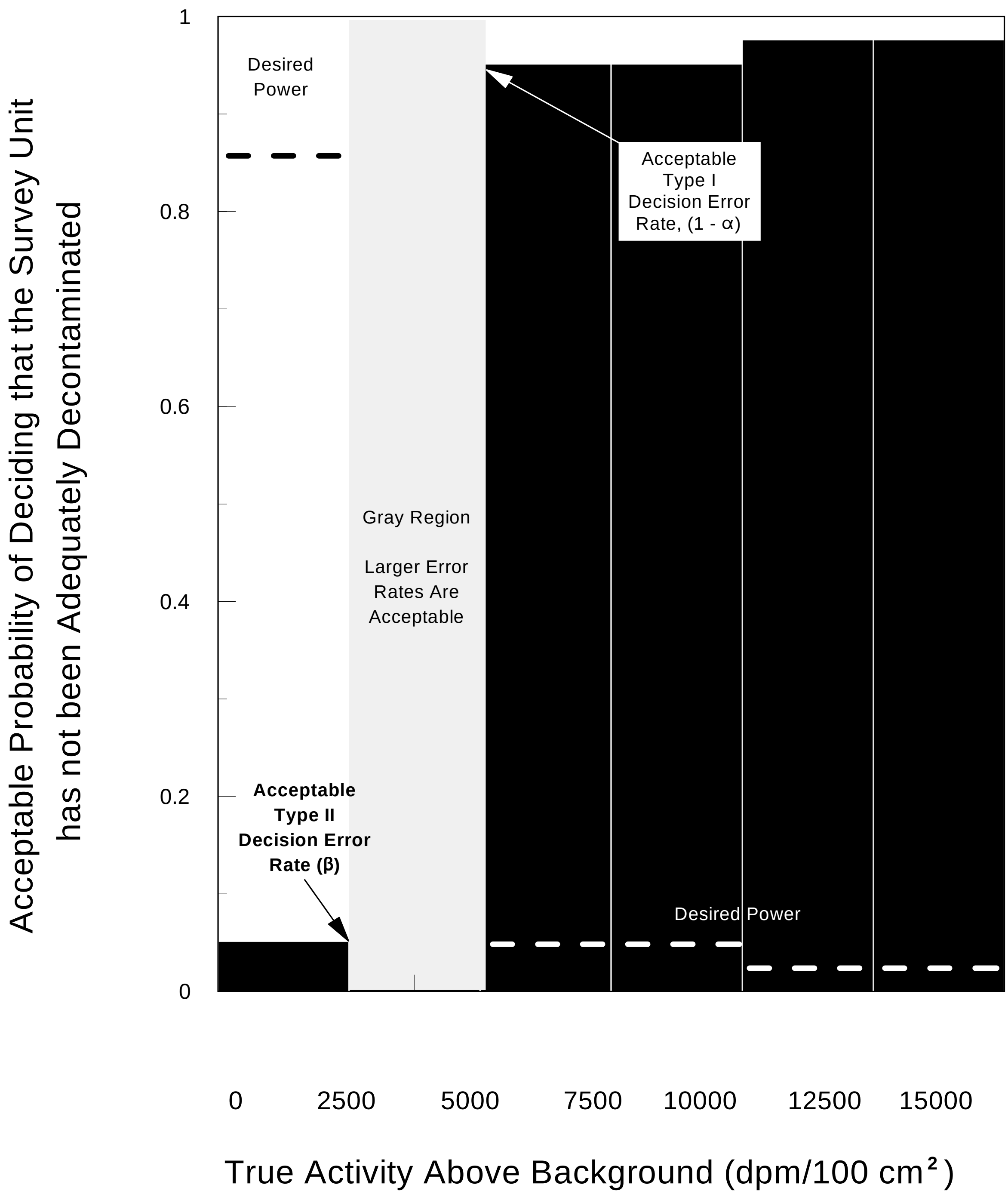


Figure A.5 Power Chart for the Class 1 Interior Concrete Survey Unit

A.3.3 Specify Sample Collection and Analysis Procedures
(Chapter 7)

In the Class 3 exterior survey unit soil cores were taken to a depth of 7.5 cm (3 in.) based on development of DQOs, the conceptual site model, and the assumptions used to develop the DCGLs. Each sample was labeled with the location code, date and time of sampling, sealed in a plastic bag, and weighed prior to shipment to the analytical laboratory. At the laboratory, the samples were weighed, dried, and weighed again. The samples were ground to a uniform particle size to homogenize the samples consistent with the modeling assumptions used to develop the DCGLs. One hundred gram (100 g) aliquots were gamma counted using a germanium detector with multichannel analyzer.

The decision to use radionuclide-specific measurements for soil means that the survey of the Class 3 exterior soil surface survey unit was designed for use with the one-sample Sign test.

A.3.4 Provide Information on Survey Instrumentation and Techniques
(Chapter 6)

A gas flow proportional counter with 20 cm^2 probe area and 16% 4π response was placed on the surface at each direct measurement location, and a one minute count taken. Calibration and background were checked before and after each series of measurements. The $DCGL_W$, adjusted for the detector size and efficiency, is:

$$(5{,}000 \text{ dpm}/100 \text{ cm}^2)\ (0.20)\ (0.16) = 160 \text{ cpm} \qquad \text{A-1}$$

The decision to use total activity measurements for interior surfaces means that the survey of all the interior survey units was designed for use with the two-sample WRS test for comparison with an appropriate reference area.

A.3.5 Determine Numbers of Data Points
(Section 5.5.2.2)

This facility contains 15 survey units consisting of interior concrete surfaces, interior drywall surfaces, exterior surface soil, and exterior paved surfaces.

<u>Concrete Surfaces</u>

The site has 12 interior concrete survey units to be compared with 1 reference area. The same type of instrument and method were used to perform measurements in each area.

The lower bound of the gray region is selected to be one-half the DCGL, and Type I and Type II error values (α and β) of 0.05 were selected. The number of samples/measurements to be obtained, based on the requirements of the statistical tests, was determined using Equation 5-1 in Section 5.5.2.2:

$$N = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{3(P_r - 0.5)^2} \qquad \text{A-2}$$

From Table 5.2 it is found that $Z_{1-\alpha} = Z_{1-\beta} = 1.645$ for $\alpha = \beta = 0.05$.

The parameter P_r depends on the relative shift, Δ/σ. The width of the gray region, Δ, in Figure A.5 is 4,200 Bq/m^2 (2,500 dpm/100 cm^2), which corresponds to 80 cpm. Data from previous scoping and characterization surveys indicate that the background level is 45 ± 7 (1σ) cpm. The standard deviation of the contaminant in the survey unit (σ_s) is estimated at ± 20 cpm. When the estimated standard deviation in the reference area and the survey units are different, the larger value should be used to calculate the relative shift. Thus, the value of the relative shift, Δ/σ, is (160-80)/20 or 4.[2] From Table 5.1, the value of P_r is approximately 1.000.

The number of data points for the WRS test of each combination of reference area and survey units according to the allocation formula was:

$$N = \frac{(1.645 + 1.645)^2}{3(1.000 - 0.5)^2} = 14.4 \qquad \text{A-3}$$

Adding an additional 20% and rounding up yielded 18 data points total for the reference area and each survey unit combined. Note that the same result is obtained by simply using Table 5.3 or Table I.2b with $\alpha = \beta = 0.05$ and $\Delta/\sigma = 4$. Of this total number, 9 were planned from the reference area and 9 from each survey unit. The total number of measurements calculated based on the statistical tests was 9 + (12)(9) = 117.

A.3.6 Evaluate the power of the statistical tests against the DQOs.
(Appendix I.9.2)

Using Equation I-8, the prospective power expected of the WRS test was calculated using the fact that 9 samples were planned in each of the survey units and the reference area. The value of σ_s was taken to be 20 cpm, the larger of the two values anticipated for the reference area (7 cpm) and the survey unit (20 cpm). This prospective power curve is shown in Figure A.6.

---

[2] Ordinarily Δ/σ would be adjusted to a value between 1 and 3. For this example the adjustment was not made.

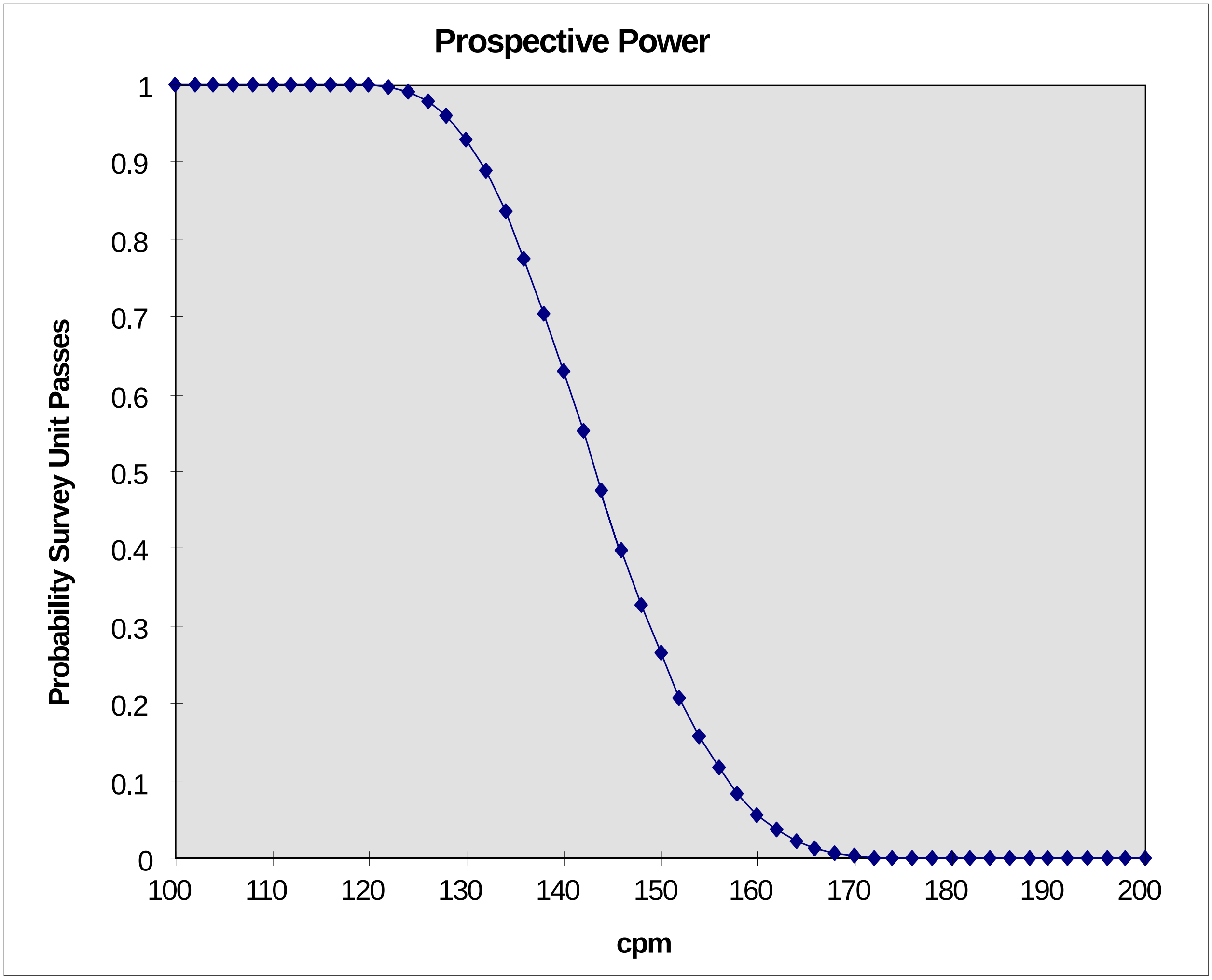


Figure A.6 Prospective Power Curve for the Class 1 Interior Concrete Survey Unit

A.3.7 Ensure that the Sample Size is Sufficient for Detecting Areas of Elevated Activity (Chapter 5.5.2.4)

The Class 1 concrete interior survey units each have an area of 140 m^2 (Figure A.7). The distance between measurement locations in these survey units was:

$$L = \sqrt{\frac{A}{0.866n}} = \sqrt{\frac{140}{0.866\ (10)}} = 4.2\ m \qquad \text{A-4}$$

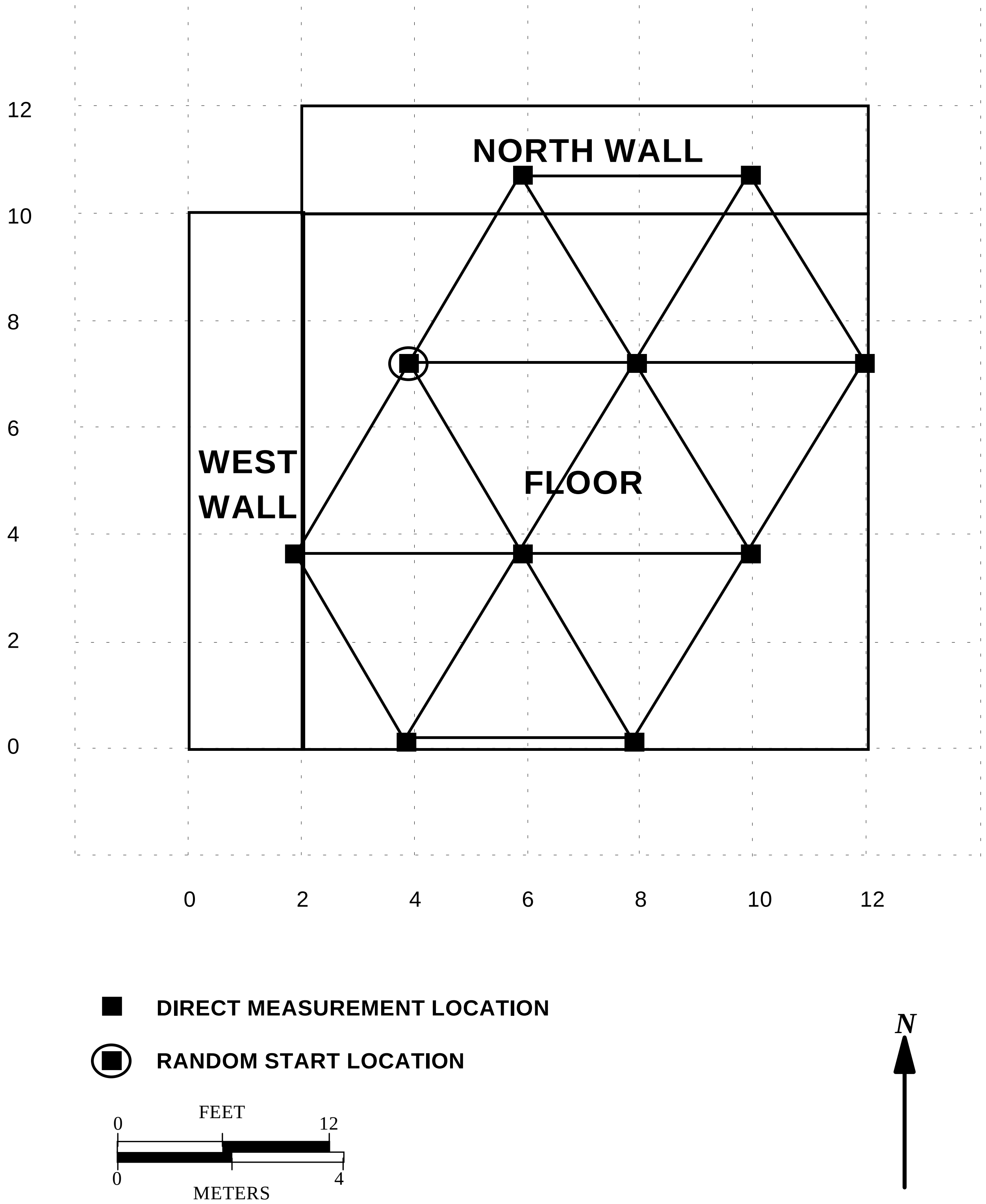


Figure A.7 Measurement Grid for the Class 1 Interior Concrete Survey Unit

The result for L was rounded *down* to the nearest meter, giving L = 4 m. This resulted in an area between sampling points of $0.866L^2 = 13.9\ m^2$. The $DCGL_W$ of 8,300 Bq/m^2 (5,000 dpm/100 cm^2) was well above the scanning MDC of 6,000 Bq/m^2 (3,600 dpm/100 m^2) for the least sensitive of the two scanning instruments (the floor monitor). Therefore, no adjustment to the number of data points to account for areas of elevated activity was necessary.

A.3.8 Specify Sampling Locations
(Chapter 5.5.2.5)

Two random numbers between zero and one were generated to locate the random start for the sampling grid. Using Table I.6 in Appendix I, 0.322467 and 0.601951 were selected. The random start for triangular sampling pattern was found by multiplying these numbers by the length of the reference grid X and Y axes:

$$X = 0.322467 \text{ x } 12 \text{ m} = 3.9 \tag{A-5}$$
$$Y = 0.601951 \text{ x } 12 \text{ m} = 7.2 \tag{A-6}$$

The first row of measurement locations was laid out at 4m intervals parallel to one axis of the reference grid. The second row was positioned (0.866)(4) = 3.5 m from the first row, with measurement locations offset by 2 m from those in the first row. The measurement grid is shown in Figure A.7. When the measurement grid was constructed it was found that 10 measurement locations were identified within the boundaries of the survey unit, which is greater than the 9 measurement locations calculated to be required for the statistical test. Because the spacing between the measurements (L) is important for identifying areas of elevated activity, *all* of the identified sampling locations should be used.

A.3.9 Develop Quality Control Procedures
(Section 4.9)

A.3.10 Document Results of Planning into a Quality Assurance Project Plan
(Section 9.2)

A.4 Conducting Surveys

A.4.1 Perform Reference (Background) Area Measurements and Scanning
(Chapter 6)

A.4.2 Collect and Analyze Samples
(Chapter 7)

A.5 Evaluating Survey Results

A.5.1 Perform Data Quality Assessment

(Chapter 8.2)

The data from the one Class 1 interior concrete survey unit and its associated reference area are given in Table A.1. Since ten sampling locations were identified, ten results are listed for the survey unit.[3] The average measurement in the survey unit is 206 cpm, and in the reference area the average is 46 cpm. The means and the medians are nearly equal in both cases. The standard deviations are also consistent with those estimated during the survey design. The survey unit clearly contains residual radioactivity close to the $DCGL_W$ of 160 cpm (calculated using Equation A-1).

Table A.1 Class 1 Interior Concrete Survey Unit and Reference Area Data

	Reference Area (cpm)	Survey Unit (cpm)
	45	205
	36	207
	32	203
	57	196
	46	211
	60	208
	39	172
	45	216
	53	233
	42	209
mean	46	206
standard deviation	9	15.4
median	45	207.5

[3] There are also ten results listed for the reference area. This is only because there were also ten locations identified there when the grid was laid out. Had nine locations been found, the survey would proceed using those nine locations. There is no requirement that the number of sampling locations in the survey unit and reference area be equal. It is only necessary that at least the minimum number of samples required for the statistical tests is obtained in each.

The stem and leaf displays (see Appendix I.7) for the data appear in Table A.2. They indicate that the data distributions are unimodal with no notable asymmetry. There are two noticeably extreme values in the survey unit data set, at 172 and 233 cpm. These are both about 2 standard deviations from the mean. A check of the data logs indicated nothing unusual about these points, so there was no reason to conclude that these values were due to anything other than random measurement variability.

Table A.2 Stem and Leaf Displays for Class 1 Interior Concrete Survey Unit

Reference Area				
30	6	2	9	
40	5	5	6	2
50	7	3		
60	0			

Survey Unit					
170	2				
180					
190	6				
200	5	7	3	8	9
210	1	6			
220					
230	3				

A Quantile-Quantile plot (see Appendix I.8) of this data, shown in Figure A.8, is consistent with these conclusions. The median and spread of the survey unit data are clearly above those in the reference area. The middle part of the curve has no sharp rises. However, the lower and upper portion of the curve both show a steep rise due to the two extreme measurements in the survey unit data set.

A.5.2 Conduct Elevated Measurement Comparison

(Section 8.5.1)

The $DCGL_W$ is 160 cpm above background. Based on an area between measurement locations 13.9 m^2 for L = 4 m, the area factor (from Table 5.7) is approximately 1.5. This means the $DCGL_{EMC}$ is 240 cpm above background. Even without subtracting the average background value of 46, there were no survey unit measurements exceeding this value. All of the survey unit measurements exceed the $DCGL_W$ and six exceed 206 cpm—the $DCGL_W$ plus the average background. If any of these data exceeded three standard deviations of the survey unit mean, they might have been considered unusual, but this was not the case. Thus, while the amount of residual radioactivity appeared to be near the release criterion, there was no evidence of smaller areas of elevated residual radioactivity.

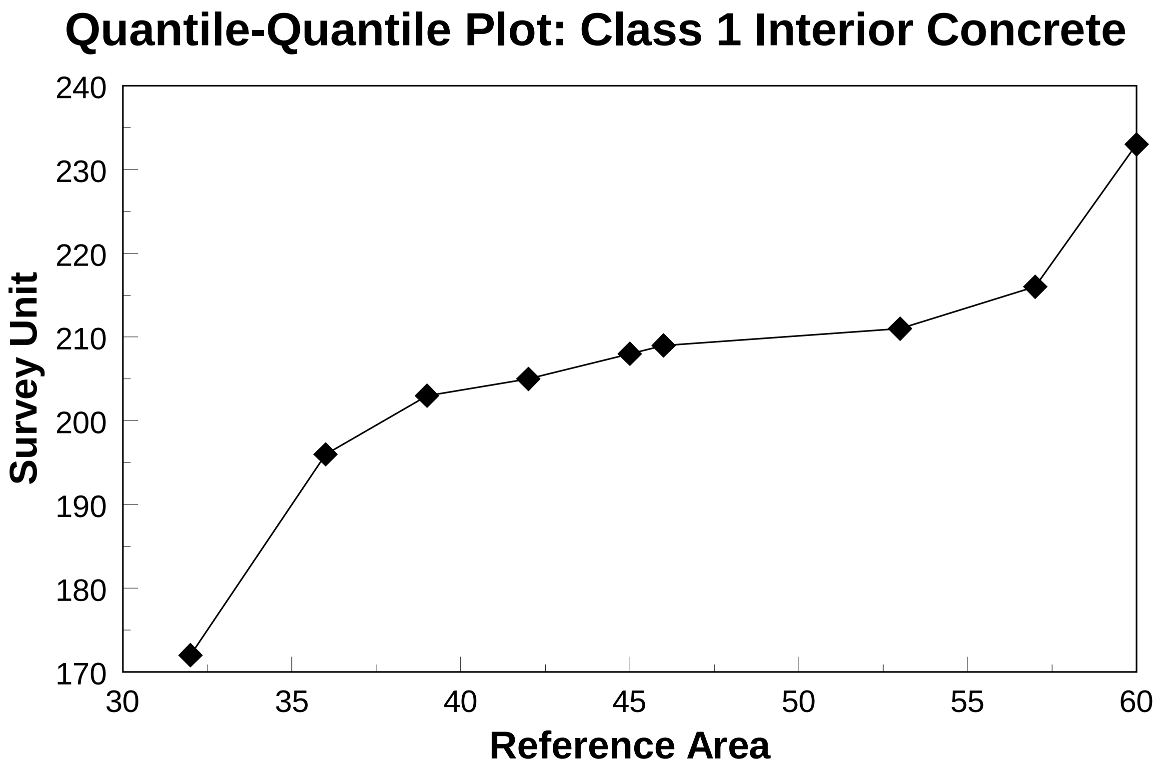


Figure A.8 Quantile-Quantile Plot for the Class 1 Interior Concrete Survey Unit

A.5.3 Conduct Statistical Tests
(Section 8.3, 8.4)

For the Class 1 interior concrete survey unit, the two-sample nonparametric statistical tests of Section 8.4 were appropriate since, although the radionuclide of concern does not appear in background, radionuclide specific measurements were not made. This survey unit was classified as Class 1, so the 10 measurements performed in the reference area and the 10 measurements performed in the survey unit were made on random start triangular grids.

Table A.3 shows the results of the twenty measurements in the first column. The average and standard deviation of the reference area measurements were 46 and 9, respectively. The average and standard deviation of the survey unit measurements were 206 and 15, respectively.

Table A.3 WRS Test for Class 1 Interior Concrete Survey Unit

Data	Area	Adjusted Data	Ranks	Reference Area Ranks
45	R	205	7.5	7.5
36	R	196	4	4
32	R	192	3	3
57	R	217	15	15
46	R	206	9	9
60	R	220	16	16
39	R	199	5	5
45	R	205	7.5	7.5
53	R	213	13	13
42	R	202	6	6
211	S	211	12	0
208	S	208	10	0
172	S	172	1	0
216	S	216	14	0
233	S	233	18	0
209	S	209	11	0
237	S	237	19	0
176	S	176	2	0
253	S	253	20	0
229	S	229	17	0
Sum=			210	86

The analysis proceeded as described in Section 8.6.3. In the “Area” column, the code "R" is inserted to denote a reference area measurement, and "S" to denote a survey unit measurement. In the “Data” column, the data were simply listed as obtained. The Adjusted Data were obtained by adding the $DCGL_W$ to the reference area measurements and leaving the survey unit measurements unchanged. The ranks of the Adjusted Data appear in the “Ranks” column. They range from 1 to 20, since there is a total of 20 (10+10) measurements. The sum of *all* of the ranks is 20(20+1)/2 = 210. It is recommended to check this value as a guard against errors in the rankings.

The “Reference Area Ranks” column contains only the ranks belonging to the reference area measurements. The total is 86. This was compared with the entry in Table I.4 for $\alpha = 0.05$, with $n = 10$ and $m = 10$. This critical value is 127. Thus, the sum of the reference area ranks was *less* than the critical value and the null hypothesis—that the survey unit concentrations exceed the $DCGL_W$—was accepted.

Again, as in Section 8.6.3, the retrospective power curve for the WRS test was constructed as described in Appendix I.9, using Equations I-8, I-9, and I-10, together with the actual number of concentration measurements obtained, N. The power as a function of Δ/s was calculated using the observed standard deviation, s = 15.4, in place of σ. The values of Δ/σ were converted to cpm using:

$$\text{cpm} = DCGL_W - (\Delta/\sigma)(\text{observed standard deviation}) \qquad \text{A-7}$$

The results for this example are plotted in Figure A.9, showing the probability that the survey unit would have passed the release criterion using the WRS test versus cpm of residual radioactivity. This curve shows that the data quality objectives were easily met. The curve shows that a survey unit with less than about 130 cpm above background would almost always pass and that a survey unit with more than about 170 cpm above background would almost always fail.

A.5.4 Estimate Amount of Residual Radioactivity

(Chapter 8.5.2.1)

The amount of residual radioactivity in the survey unit above background was estimated following the WRS test using the difference between the mean measurement in the survey unit and the mean measurement in the reference area: δ = 206 - 46 = 160. This was converted to a surface area activity concentration of 8,300 Bq/m^2 (5,000 dpm/100 cm^2), which is just at the limiting value, $DCGL_W$.

The difference in the median measurements (207.5 - 45 = 162.5) was converted to a surface activity concentration of 8,500 Bq/m^2 (5,100 dpm/100 cm^2). This slightly exceeds the $DCGL_W$.

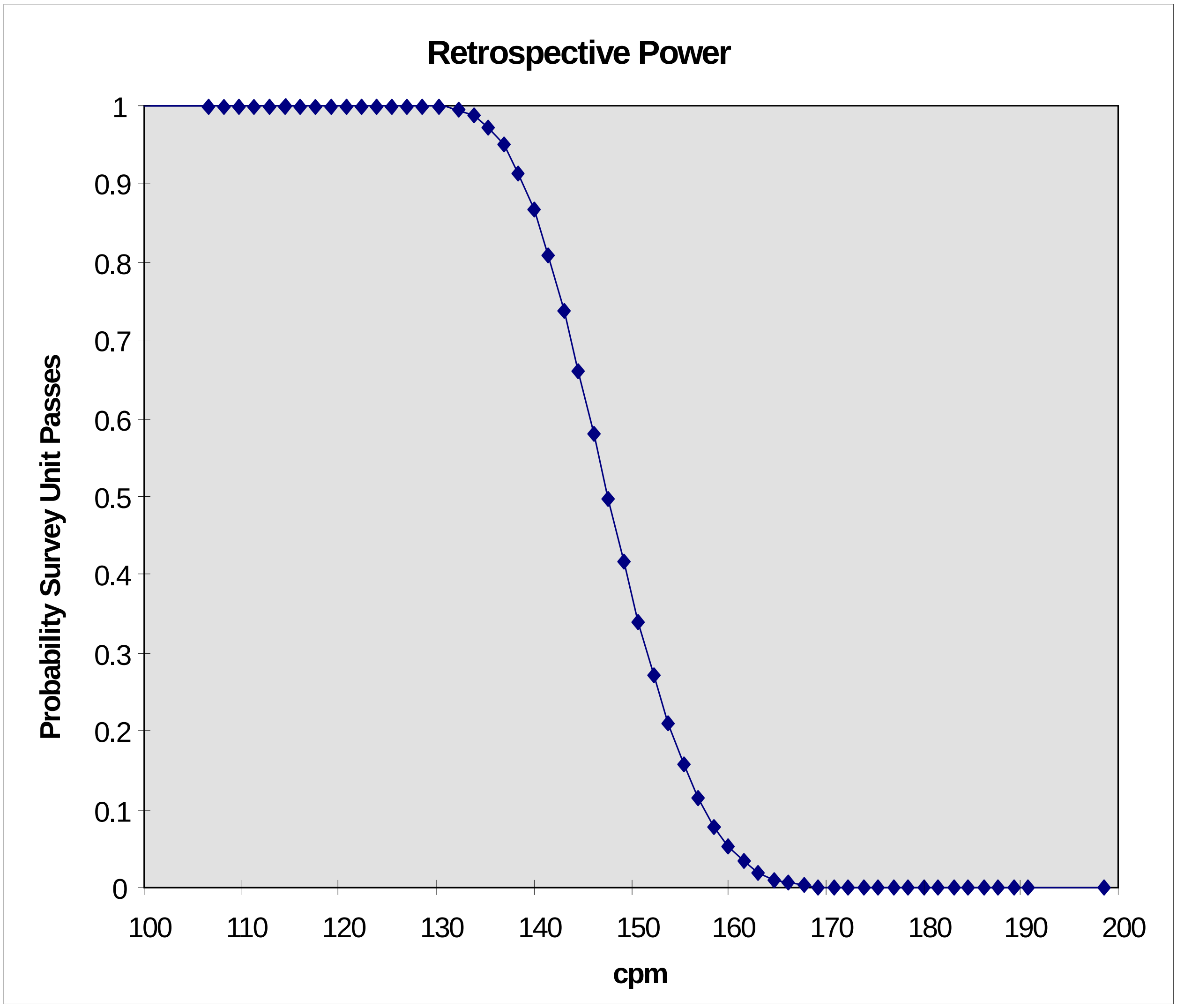


Figure A.9 Retrospective Power Curve for the Class 1 Interior Concrete Survey Unit