Designation: D6982 − 22

Standard Practice for Detecting Hot Spots Using Point-Net (Grid) Search Patterns[1]

This standard is issued under the fixed designation D6982; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice provides equations and nomographs, and a reference to a computer program, for calculating probabilities of detecting hot spots (that is, localized areas of soil or groundwater contamination) using point-net (that is, grid) search patterns. Hot spots, more generally referred to as targets, are presumed to be invisible on the ground surface. Hot spots may include former surface impoundments and waste disposal pits, as well as contaminant plumes in groundwater or the vadose zone.

1.2 For purposes of calculating detection probabilities, hot spots or buried contaminants are presumed to be elliptically shaped when projected vertically to the ground surface, and search patterns are square, rectangular, or rhombic. Assumptions about the size and shape of suspected hot spots are the primary limitations of this practice, and must be judged by historical information. A further limitation is that hot spot boundaries are usually not clear and distinct.

1.3 In general, this practice should not be used in lieu of surface geophysical methods for detecting buried objects, including underground utilities, where such buried objects can be detected by these methods (see Guide D6429).

1.4 Search sampling would normally be conducted during preliminary investigations of hazardous waste sites or hazardous waste management facilities (see Guide D5730). Sampling may be conducted by drilling or by direct-push methods. In contrast, guidance on sampling for the purpose of making statistical inferences about population characteristics (for example, contaminant concentrations) can be found in Guide D6311.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D5730 Guide for Site Characterization for Environmental Purposes With Emphasis on Soil, Rock, the Vadose Zone and Groundwater (Withdrawn 2013)[3]

D6051 Guide for Composite Sampling and Field Subsampling for Environmental Waste Management Activities

D6311 Guide for Generation of Environmental Data Related to Waste Management Activities: Selection and Optimization of Sampling Design

D6429 Guide for Selecting Surface Geophysical Methods

3. Terminology

3.1 *Definitions:*

3.1.1 *hot spot*—a localized area of soil or groundwater contamination.

3.1.1.1 *Discussion*—A hot spot may be considered as a discrete volume of buried waste or contaminated soil where the concentration of a contaminant of interest exceeds some prespecified threshold value. Although hot spots are more likely to have variable sizes and shapes and not have clear and distinct boundaries, ellipitically shaped hot spots or targets with well-defined edges are assumed for the purposes of calculating detection probabilities. The assumption that hot spots have elliptical shapes is not inconsistent with known historical patterns of contaminant distribution.

3.1.2 *sampling density*—the number of soil borings (that is, sampling points) per unit area.

3.1.3 *semi-major axis, a*—one half the length of the long axis of an ellipse. For a circle, this distance is simply the radius.

[1] This practice is under the jurisdiction of ASTM Committee D34 on Waste Management and is the direct responsibility of Subcommittee D34.01.01 on Planning for Sampling.

Current edition approved May 1, 2022. Published May 2022. Originally approved in 2003. Last previous edition approved in 2016 as D6982 – 09 (2016). DOI: 10.1520/D6982-22.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

3.1.4 *semi-minor axis, b*—one half the length of the short axis of an ellipse.

3.1.5 *target*—the object or "hot spot" that is being searched for.

3.1.6 *threshold concentration*—the concentration of a contaminant above which a hot spot is considered to be detected.

3.1.7 *unit cell*—the smallest area into which a grid can be divided so that these areas have the same shape, size, and orientation. For a triangular grid, the unit cell is a 60°/120° rhombus comprised of two equilateral triangles with a common side.

3.2 *Symbols:*

3.2.1 a—length of the semi-major axis of an ellipse

3.2.2 b—length of the semi-minor axis of an ellipse

3.2.3 A_T—area of target or hot spot. For an ellipse, $A_T = \pi ab$.

3.2.4 A_S—search area

3.2.5 S—the "shape" of an elliptical target (that is, the ratio of the length of the semi-minor axis to the length of the semi-major axis of an ellipse, b/a)

3.2.6 G—the distance between nearest grid nodes of a unit cell

3.2.7 Q—the ratio of the length of the long side of a rectangular grid cell to the length of the short side

3.2.8 A_C—the area of the unit cell. For a square, $A_{sq} = G^2$. For a rectangle $A_{re} = Q{\cdot}G^2$. For a 60°/120° rhombus, $A_{rh} = [(\sqrt{3})/2]G^2$. The inverse of A_C is the sampling density

3.2.9 β—the probability of not detecting a hot spot

3.2.10 $P(hit)$—probability of detection (that is, $1 - \beta$)

4. Significance and Use

4.1 Search sampling strategies have found wide utility in geologic exploration where drilling is required to detect subsurface mineral deposits, such as when drilling for oil and gas. Using such strategies to search for buried wastes and subsurface contaminants, including volatile organic compounds, is a logical extension of these strategies.

4.2 Systematic sampling strategies are often the most cost-effective method for searching for hot spots.

4.3 This practice may be used to determine the risk of missing a hot spot of specified size and shape given a specified sampling pattern and sampling density.

4.4 This practice may be used to determine the smallest hot spot that can be detected with a specified probability and given sampling density.

4.5 This practice may be used to select the optimum grid sampling strategy (that is, sampling pattern and density) for a specified risk of not detecting a hot spot.

4.6 By using the algorithms given in this practice, one can balance the cost of sampling versus the risk of missing a hot spot.

4.7 Search sampling patterns may also be used to optimize the locations of additional groundwater monitoring wells or vadose zone monitoring devices.

5. Assumptions

5.1 One or more targets or hot spots exist and are equally likely to occur in any part of the search area.

5.2 When projected vertically upward to a level ground surface, the target appears as an ellipse or a circle (Fig. 1). The probable size and shape of a hot spot can only be guessed from past site or facility records, known layout of the site or facility, and personal knowledge.

5.3 The search pattern is either a square, a rectangular, or an equilateral triangular grid. Borings are made at the intersections of grid lines (that is, nodes) (Fig. 2).

5.4 Borings or direct-push devices are directed downward vertically and the detection of the target is unambiguous. Such an assumption presumes that the full length of a boring would be subject to analysis as contiguous intervals of the boring. If sampling intervals are discontinuous, then contamination might be missed if it occurred between sampled intervals. If sampling intervals are too long, then a hot spot may not be detected because of dilution of a hot spot with less contaminated portions of the sampled interval. The criteria for detection of contaminants may be prespecified threshold concentrations (for example, screening levels) that would trigger further investigation of sites or facilities.

5.5 The area of the bore hole or direct-push device is infinitely small compared to the target area. The algorithms used in this practice assume that bore holes or direct-push devices have no area, but rather are vertical lines projected downward from grid nodes.

6. Preliminary Considerations

6.1 Before designing a hot spot detection strategy, a preliminary investigation of the area containing possible hot spots or targets should be conducted. From historical records, physical layout of buildings and equipment, known transportation pathways, landscape features, and eyewitness accounts, one

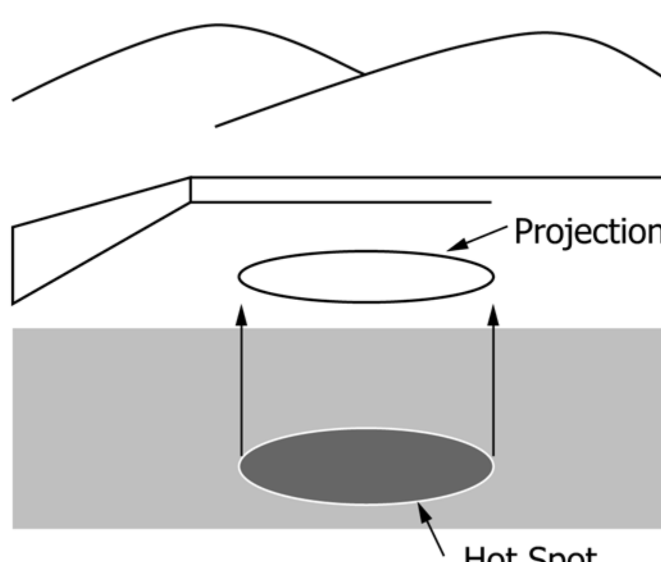

FIG. 1 Projection of Boundaries of Subsurface Contamination to the Ground Surface

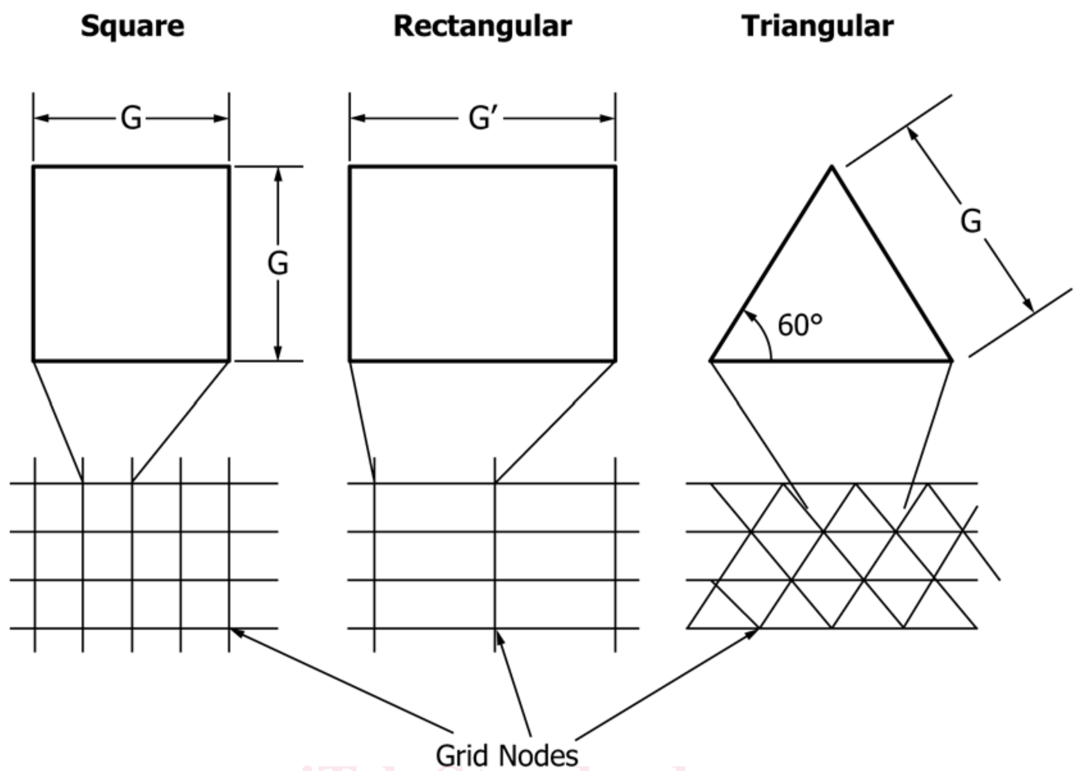

FIG. 2 Grid Patterns for Detecting Hot Spots. Borings are Made at the Grid Nodes

may be able to identify areas with a high probability of subsurface contamination. Areas with different expected probabilities of detection of a hot spot or other target should be clearly mapped.

6.2 Within areas of relatively uniform expected probability of hot spot or target detection, sampling grids of prespecified grid spacing *G* and type (for example, square, rectangular, or triangular) may be overlain. Areas with smaller hot spots should have correspondingly higher sampling densities compared to areas with large hot spots. However, areas with greater hazard from missing a hot spot should also have correspondingly higher sampling densities than areas with a lesser hazard. Ideally, the starting point for each grid and its orientation should be randomly determined.

6.3 When searching for hot spots, threshold concentrations for detection may be established by a regulatory authority. Whether or not a threshold concentration is exceeded will depend upon the physical distribution of the contaminant, the volume of the sampling device, the sampling intervals selected, and the sensitivity of the analysis. If contamination occurs in a discrete layer, then the probability of detecting a hot spot will decrease with increasing volume of material sampled in a bore hole or if the sampling interval exceeds the depth of the discrete hot spot layer. The analytically determined contaminant concentration may then be less than the threshold concentration because of the dilution of the hot spot layer with uncontaminated layers of soil or waste. Further, a hot spot confined to a discrete layer may be missed entirely by not sampling that layer. For this reason, continuous sampling is recommended.

6.4 Detection of contaminant levels in samples above threshold concentrations may trigger more detailed sampling to better define the spatial extent of hot spots or buried contamination. Again, a grid sampling strategy will be the most efficient.

7. Determining Hot Spot Detection Probabilities

7.1 *Case I*—If the longest dimension of an elliptical target is less than or equal to the grid spacing (that is, $2a \leq G$), then the target can only be hit once and the probability *P* of detecting the hot spot is simply equal to the ratio of the area of the target A_T to the area of the unit cell A_C (that is, $P = A_T/A_C$).

7.2 *Case 2*—If the longest dimension of an elliptical target is greater than the grid spacing (that is, $2a > G$), then the target may be hit more than once. In this case, algorithms developed by Singer and Wickman (**1**)[4] employing affine transformations and programmed in FORTRAN by Singer (**2**) are required to calculate the exact probability of detecting the target. This program is limited to ellipses having a shape *S* between 0.05 and 1.0 and the ratio *a/G* between 0.05 and 1.0. Singer's algorithms have been adapted by J. R. Davidson (**3**) to the personal computer (PC) running under the MS DOS operating system. Supporting documentation for this program, ELIPGRID-PC, is available from Oak Ridge National Laboratory (**4**, **5**).

7.3 *Randomly Oriented Elliptical Target*—The probability of detecting a target, *P(hit)*, of a specified size *a* shape *S* and for

[4] The boldface numbers in parentheses refer to the list of references at the end of this standard.

a specified grid *G* spacing can be obtained from nomographs shown in Figs. 3 and 4 for square and equilateral triangular grid sampling patterns, respectively. Data for these nomographs were generated using the ELIPGRID-PC program. To use these graphs, first calculate the ratio *a/G*. Then draw a vertical line from the point represented by the ratio *a/G* on the *x*-axis of the graph to the curve representing the prespecified shape of the ellipse. Then draw a horizontal line to the *y*-axis. For shapes other than those shown on the graphs, one must interpolate between curves with closest values of *S*. The value on the *y*-axis represents the probability of at least one hit of the target. Using these same graphs, one can also determine the required grid spacing to detect an elliptical target of shape at a prespecified probability of detection. In this case, draw a horizontal line from the prespecified probability of a hit to the curve representing the prespecified shape of the ellipse. Then draw a vertical line down to the *x*-axis. From the ratio *a/G* at the point of intersection with the *x*-axis, one can determine the minimum required grid spacing. Similarly, one can also determine the smallest sized hot spot of a given shape that can be detected for a given grid spacing and probability of detection by calculating *a* from the ratio *a/G* and grid spacing *G*. Alternatively, one can use the computer program ELIPGRID-PC.

7.4 *Oriented Elliptical Target*—If the orientation of the elliptical target with respect to the grid lines is specified, then the probability of detecting the target must be determined using the computer program ELIPGRID-PC.

8. Comparing the Relative Efficiencies of Search Patterns

8.1 The efficiency of a search pattern is measured as the probability that a target (for example, hot spot) will be hit at least once. Given the same sampling density, a sampling pattern with a higher probability of hitting a target will be more efficient than a sampling pattern with a lower probability of hitting the same target. The relative efficiency, *RE*, of one sampling pattern over another when searching for a target is measured as the percent difference in the efficiency of two equivalent density sampling patterns. For example, $RE = 100\,\%\ (P_{TRI} - P_{SQR})/P_{SQR}$ where P_{TRI} and P_{SQR} are the probabilities of detecting a target with an equilateral triangular grid and a square grid, respectively. By extension, for the same probability of detecting a target, a more efficient sampling pattern will require fewer borings, and will thus be more economical. In this section, the relative efficiencies of hitting randomly oriented (that is, orientation unknown) and oriented elliptical targets of prespecified size and shape are compared using different sampling patterns having equivalent sampling densities.

8.2 *Randomly Oriented Elliptical Targets:*

8.2.1 *Square versus Equilaterial Triangular Grid*—When the criterion for detection is one or more hits, the equilateral triangular grid is up to 6 % more efficient than the square grid (for a circular target where *a/G* = 0.55) while a square grid is never more than 0.2 % more efficient (**6**). Efficiencies are the same for *a/G* ratios less than 0.5 since a target can be hit no

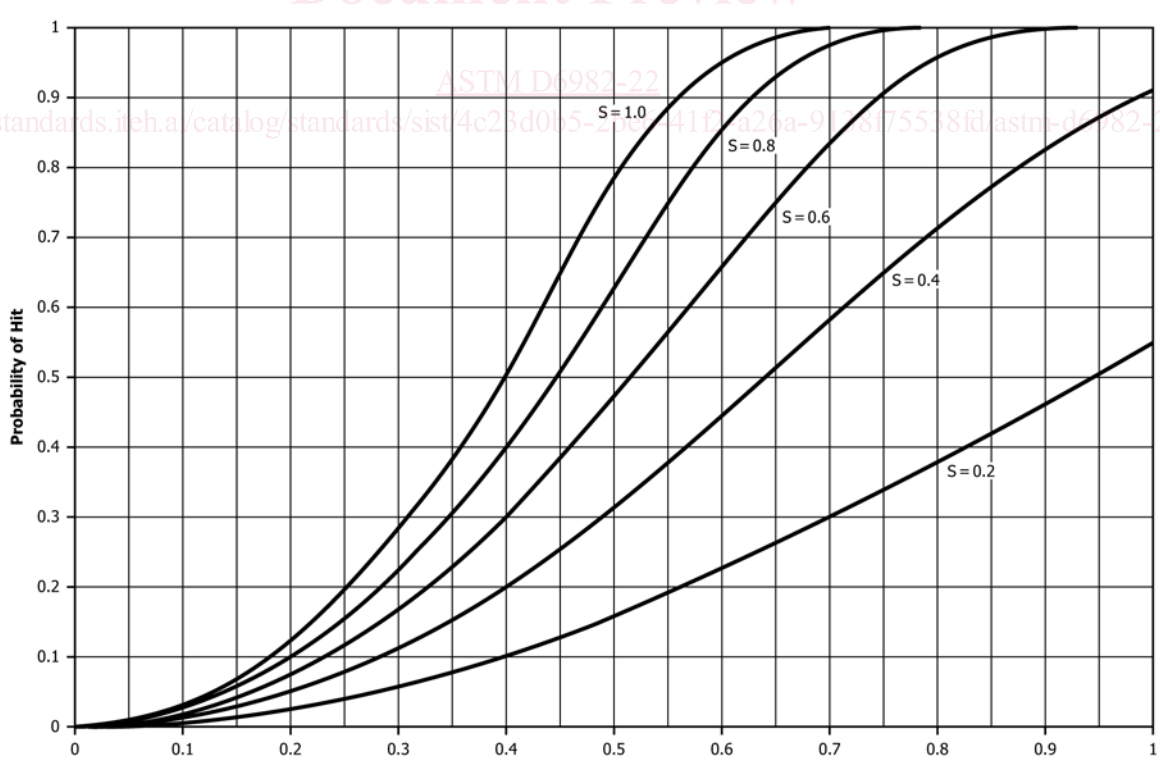

FIG. 3 Nomograph Relating the Probability of Detecting a Single Hot Spot to the Ratio *a/G* for Selected Shapes (*b/a*) Using a Square Grid with Grid Spacing *G*

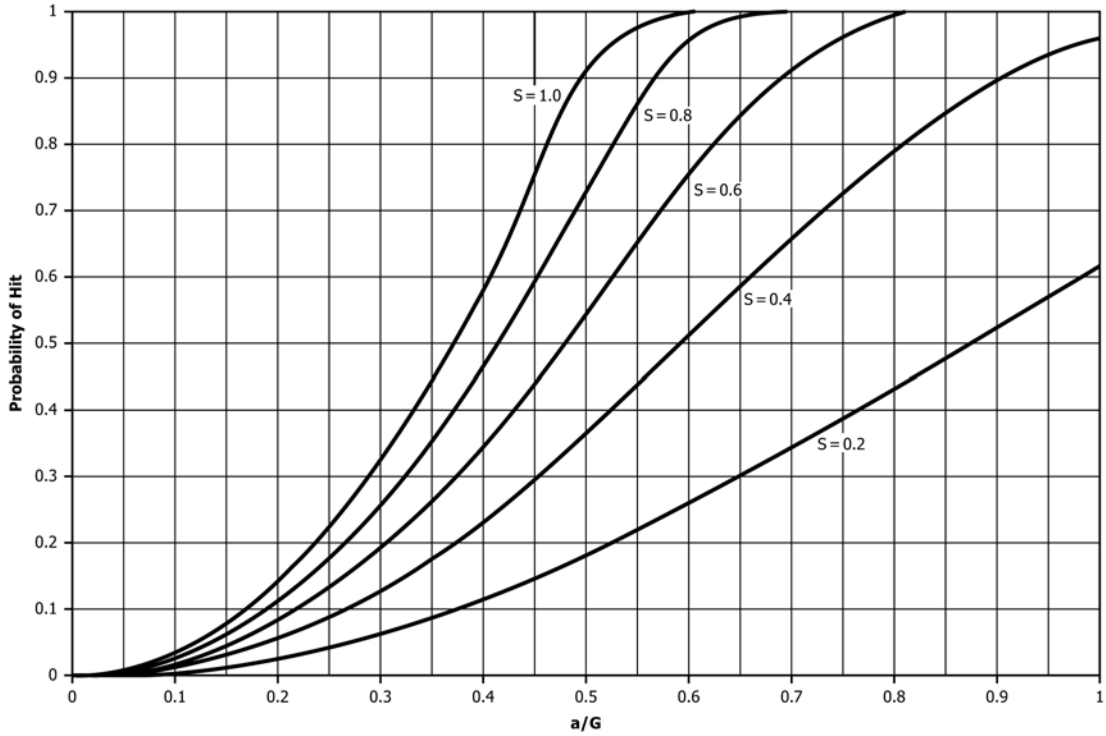

FIG. 4 Nomograph Relating the Probability of Detecting a Single Hot Spot to the Ratio *a/G* for Selected Shapes (*b/a*) Using a Triangular Grid with Grid Spacing *G*

more than once. For $a/G > 0.5$ and if two or more hits are required for detection, then a square grid is overall more efficient than an equilateral triangular grid.

8.2.2 *Point-Net versus Random*—When one or more hits are required for detection, then point-net search sampling strategies are more efficient than random sampling strategies for detecting subsurface contamination. This can be easily shown by comparing the probability of detecting a hot spot using a grid sampling approach to the probability of detecting a hot spot by random sampling (see Appendix X1). Where two or more hits are required for detection and $a/G < 0.5$, then a random search is more efficient (**6**).

8.3 *Targets with Known Orientation:*

8.3.1 *Square versus Equilateral Triangular Grid*—When one or more hits are required for detection, an equilateral triangular grid is generally more efficient when the angle of orientation is close to 30°, 90°, or 150° whereas a square grid is more efficient when the angle of orientation is between 25° and 65° or between 115° and 155°. Between 25° and 35°, efficiencies are nearly the same. These orientations minimize the probabilities of hitting the same target more than once, which would result in less efficient sampling.

8.3.2 *Rhombic Grid versus Square and Equilateral Triangular Grids*—A rhombus is a parallelogram having opposite sides equal in length. A rhombus is also a square if the inside angles are 90°. Two equilateral triangles having a common side become a rhombus with inside angles of 60° and 120°. If the angle of orientation of an elliptical target is known, then it has been shown that a rhombic search pattern is optimal if the long diagonal of the rhombus is oriented parallel to the long axis of the elliptical target (**7**). Table 1 gives multiplication factors necessary to calculate the lengths of the diagonals of a rhombic grid for a desired probability of detecting an elliptical target of known size and shape (**8**). For a given probability of detection p, the optimum diagonal distances are $d_1 = 2a \cdot f_1(p)$ and $d_2 = 2b \cdot f_2(p)$.

TABLE 1 Multiplication Factors to Calculate the Optimum Lengths of the Diagonals of a Rhombic Grid Oriented Such That the Long Axis of the Elliptical Target is Parallel to the Longest Diagonal of the Rhombic Grid

p	$f_1(p)$	$f_2(p)$	p	$f_1(p)$	$f_2(p)$
0.05	7.37658	4.25888	0.55	2.22411	1.28409
0.10	5.21605	3.01148	0.60	2.12943	1.22943
0.15	4.25888	2.45886	0.65	2.04590	1.18120
0.20	3.68828	2.12943	0.70	1.97148	1.13823
0.25	3.29890	1.90462	0.75	1.90462	1.09964
0.30	3.01148	1.73868	0.80	1.84415	1.06472
0.35	2.78810	1.60971	0.85	1.78907	1.03292
0.40	2.60801	1.50574	0.90	1.73867	1.00382
0.45	2.45886	1.41962	0.95	1.67320	0.96602
0.50	2.33267	1.34676	1.00	1.50000	0.86602

8.3.3 *Example 1*—If there exists an elliptical target of known orientation with major axis ($2a$) of length 200 ft and minor axis ($2b$) of length 100 ft, what are the optimum lengths of the diagonals of a rhombic grid that would yield a 90 % probability of detecting this elliptical target? From Table 1, $d_1 = 200 \cdot f_1(0.90) = 200 \cdot 1.73867 = 347.7$ ft and $d_2 = 100 \cdot f_2(0.90) = 100 \cdot 1.00382 = 100.3$ ft.

9. Computing the Number of Borings and Grid Spacings for Specified Costs

9.1 Costs for conducting a search for hot spots can be roughly split between the cost of mobilization and