Range Commanders Council

Document 404-94

UNDERWATER SYSTEMS GROUP

DESIGNING A LARGE AREA UNDERWATER RANGE USING HEARING RANGE STATISTICS

WHITE SANDS MISSILE RANGE
KWAJALEIN MISSILE RANGE
YUMA PROVING GROUND
DUGWAY PROVING GROUND
ELECTRONIC PROVING GROUND
COMBAT SYSTEMS TEST ACTIVITY

ATLANTIC FLEET WEAPONS TRAINING FACILITY
NAVAL AIR WARFARE CENTER WEAPONS DIVISION
NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
NAVAL UNDERSEA WARFARE CENTER DIVISION, NEWPORT
PACIFIC MISSILE RANGE FACILITY

30TH SPACE WING
45TH SPACE WING
AIR FORCE FLIGHT TEST CENTER
AIR FORCE DEVELOPMENT TEST CENTER
AIR FORCE WEAPONS AND TACTICS CENTER
SPACE AND MISSILE SYSTEMS CENTER,
SPACE TEST AND EXPERIMENTATION PROGRAM OFFICE

August 1994

Designing a Large Area Underwater Range Using Hearing
Range Statistics

Underwater Systems Group
Range Commanders Council
White Sands Missile Range, NM 88002-5110

RCC Document 404-94

STEWS-RCC
Range Commanders Council
White Sands Missile Range, NM 88002-5110

same as block 8

NEW DOCUMENT

APPROVED FOR PUBLIC RELEASE:
DISTRIBUTION IS UNLIMITED.

The approach taken in this work was to measure hearing statistics for MK-84 pingers over a long period of time using actual Pacific Missile Range Facility (PMRF) operations conducted on the Barking Sands Underwater Range Expansion (BSURE) underwater range. From July 1989 to April 1990, hearing range statistics were generated for submarines, MK-30 targets, and torpedoes in a variety of sea states to form probability-of-detection curves. These curves were then used to predict the tracking characteristics of a large-area range.

underwater range, hearing statistics

34

UNCLAS	UNCLAS	UNCLAS	NONE

DOCUMENT 404-94

DESIGNING A LARGE AREA UNDERWATER RANGE USING HEARING RANGE STATISTICS

AUGUST 1994

Prepared by

UNDERWATER SYSTEMS GROUP
RANGE COMMANDERS COUNCIL

Published by

Secretariat
Range Commanders Council
White Sands Missile Range
New Mexico 88002-5110

TABLE OF CONTENTS

LIST OF FIGURES

TABLE OF CONTENTS (CONT'D)

Page

LIST OF FIGURES (CONT'D)

LIST OF TABLES

INTRODUCTION

At the present time, modern fleet sensors can acquire and classify targets at great distances. In general, over-the-horizon targeting capabilities, fire-control systems, new weapons, convergence-zone training, and modern naval tactics require scales of operation that far exceed the dimensions of today's underwater tracking ranges. Battle-group exercises and large-scale operational-test scenarios also use large areas of open ocean. Subelements of the battle group can extend over vast distances, and encounters with hostile submarines can occur at any time. As a result, the Navy has requirements for large area underwater-tracking ranges to be installed in deep water. The first range is a 2500-square-mile deep-water research and development (R&D) range planned for an area off of Eleuthera Island in the Bahamas. Follow-on ranges for Navy training are in the planning stages for both the Pacific Fleet and the Atlantic Fleet.

The cost of a large-area range will be directly proportional to the number of hydrophones required to provide adequate tracking coverage over the given area. This coverage, in turn, will be specified by the hearing range of the hydrophone. To generate a tracking solution, at least four hydrophones must detect and time tag the range pinger. The most commonly used pinger today is the MK-84 phase-coded pinger, which measures depth with a pressure sensor and encodes it into the transmitted ping. This pinger only requires three hearing hydrophones to generate a solution.

The hearing range of a given hydrophone can depend on a variety of different parameters: sea state, frequency, hydrophone depth, pinger-source depth, pinger-source level, hydrophone-beam pattern, pinger-motion dynamics, and bottom topography. The standard approach in designing an underwater range is to make conservative assumptions regarding the different parameters, then compute a theoretical hearing range for the hydrophone. Distances between hydrophones are then set, so there is sufficient overlap in coverage to allow at least three or four phones to hear at all times. The problem with this approach is that a lot of guesswork is involved for a large-area range. Because of the enormous costs involved in instrumenting a large area, even a seemingly small increase in hydrophone base lines can result in saving millions of dollars. It is also important to know the performance characteristics of the range in advance to be able to predict the tracking behavior.

The approach taken in this work was to measure hearing statistics for MK-84 pingers over a long period of time using actual Pacific Missile Range Facility (PMRF) operations conducted on the Barking Sands Underwater Range Expansion (BSURE) underwater range. The 880-square-mile BSURE is presently the only deep ocean tracking range available in the world. From July 1989 to April 1990, hearing-range statistics were generated for submarines, MK-30 targets, and torpedoes in a variety of sea states to form probability-of-detection curves. These curves were then used to predict the tracking characteristics of a large-area range.

DATA COLLECTION

As a standard procedure, the underwater-tracking software archives all solutions in a "solution" file and all raw pings detected by assigned hydrophones in a "raw" file. A special computer program was written to calculate post-operational statistics from this information between any given start and stop times. The program reads solutions one at a time and calculates transit times to each listening hydrophone. It then reads the raw file to see if the hydrophone actually detected a ping within a narrow window centered around the expected arrival time. Detections and no-detections are summed throughout the interval of interest as a function of the slant range to the hydrophone. Statistics for each hydrophone are kept separately, so comparisons can be made but are also lumped together to form an overall average. In the same manner, statistics are kept as a function of sea state, so a sea-state comparison can be generated. Additional software is used to sum together data collected from different targets on different days to increase the statistical base.

As an example, a typical operation used to gather data was a SUBEX. In this exercise, a submarine spends about 8 hours on-range shooting torpedoes at MK-30 targets. For each individual pinger, start and stop times were logged along with the sea state. After the operation, a program called COUNTPNG was executed which prompts the operator for times, target code, repetition rate, and file names for the pinger of interest. The program counts pings using the raw and solution files and outputs the statistical sums into a data base file having a .PNG extension. The .PNG files contain sums as a function of slant range, sea state, and hydrophone. The sums can later be added together as a function of target type to make comparisons between different pinger platforms.

The concept of averaging was heavily employed in these statistics. Hearing-range effects produced by depth, target motion, transducer-sound pressure level, and other factors that could not be controlled were averaged together by accumulating enough samples. For example, 4 hours of submarine data at a repetition rate of 1 ping per 2 seconds generates 7,200 pings which is a typical entry in the submarine data base. On the other hand, a typical torpedo entry would be only about 500 pings because of the short torpedo run time. In all, 63 MK-48 torpedoes, 27 MK-30 targets, and 25 submarines were analyzed in this fashion. This huge data base provides a very stable average and is an excellent measure of pinger variability.

HEARING-RANGE RESULTS

Figure 1 shows the average probability of detection curve for all 115 pingers measured in this study. For this plot, the mean and standard deviations were computed by treating each pinger as a statistically independent quantity having equal weight. In other words, a 4-hour submarine run was given as much equal weight as a 10-minute torpedo. This weighting was done so that the overall average would not be biased toward the characteristics displayed by a submarine where many pings were available. The actual numbers are provided in Table I. The most surprising feature of this curve is the gradual reduction in probability as the slant range increases. For instance, the reduction in detection probability from 80 to 60 percent takes place over about a 2-mile interval. This gradual reduction shows that the usual range design assumption that the hydrophone will hear every ping within a theoretical range and nothing beyond it is a poor assumption. Even at long ranges, the pinger will be detected occasionally. Notice that the standard deviation increases significantly as the slant range increases, indicating that at close range every pinger can be detected, while at long range some are audible and some are not. This standard deviation will be very helpful in deciding the optimum hydrophone spacing.

Figures 2 through 5 compare pingers mounted on MK-30 targets, submarines, and MK-48 torpedoes. Both the MK-30 and MK-48 have identical transducers and, indeed, show very similar hearing characteristics. It is interesting that the higher dynamics of the weapon motion do not result in lower probability of detection. The submarine transducer is a different variety (3WPCAT) and is driven by a different electronics package (STEP). Figure 5 shows that this pinger provides better coverage even though there seems to be a high degree of variability. Some submarines were transmitting very reliably (greater than 90 percent) out to ranges in excess of 10 nautical miles.

Figure 6 compares the hearing curves as a function of sea state. Detection ranges for sea states 1 and 2 were nearly identical with probabilities falling off sharply for sea states 3 and 4. The sea state 4 curve is biased by the stronger submarine pinger, because targets and torpedoes are not launched in high sea states. Notice that high sea-states have a maximum affect at about 9 nautical miles where detection probabilities are lowered by as much as 20 percent.

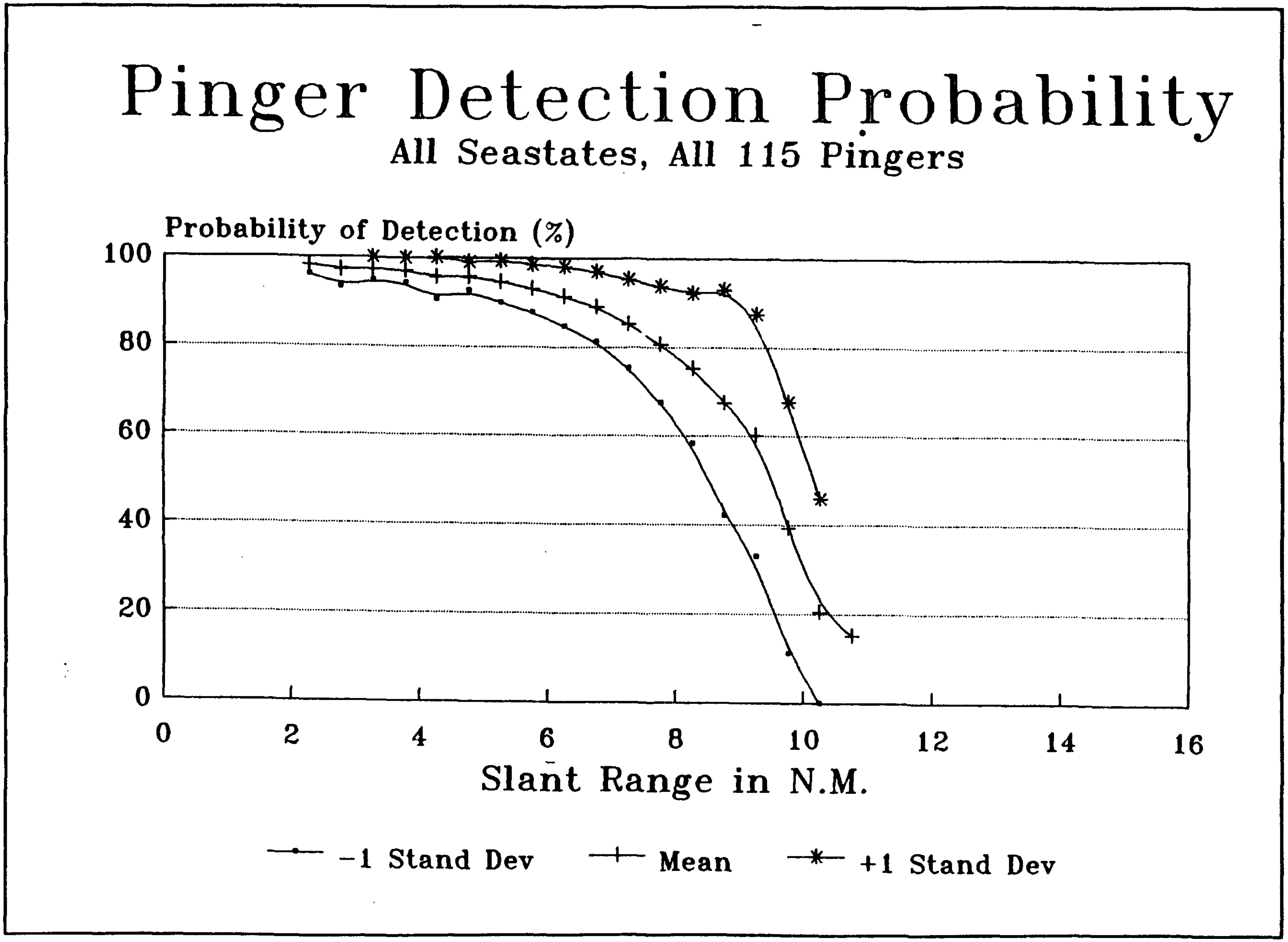

Figure 1. Average probability of detection curve for all 115 pingers.

TABLE I. PINGER, DETECTION PROBABILITY (All Sea States, All 115 Pingers)			
Slant Range (Naut Mi)	Mean (%)	Standard Deviation (%)	No. of Samples
2.25	98.2	2.1	69
2.75	97.2	3.9	9
3.25	97.4	2.5	110
3.75	97.0	2.8	111
4.25	95.5	4.9	113
4.75	95.8	3.2	115
5.25	94.6	4.7	114
5.75	93.1	5.4	115
6.25	91.4	6.7	115
6.75	89.1	7.9	115
7.25	85.2	10.0	115
7.75	80.6	13.2	114
8.25	75.2	16.9	112
8.75	67.5	25.5	108
9.25	60.2	27.3	74
9.75	39.4	28.3	53
10.25	20.4	25.6	42
10.75	15.2	21.9	32
11.25	6.8	10.0	19
11.75	6.9	9.9	18

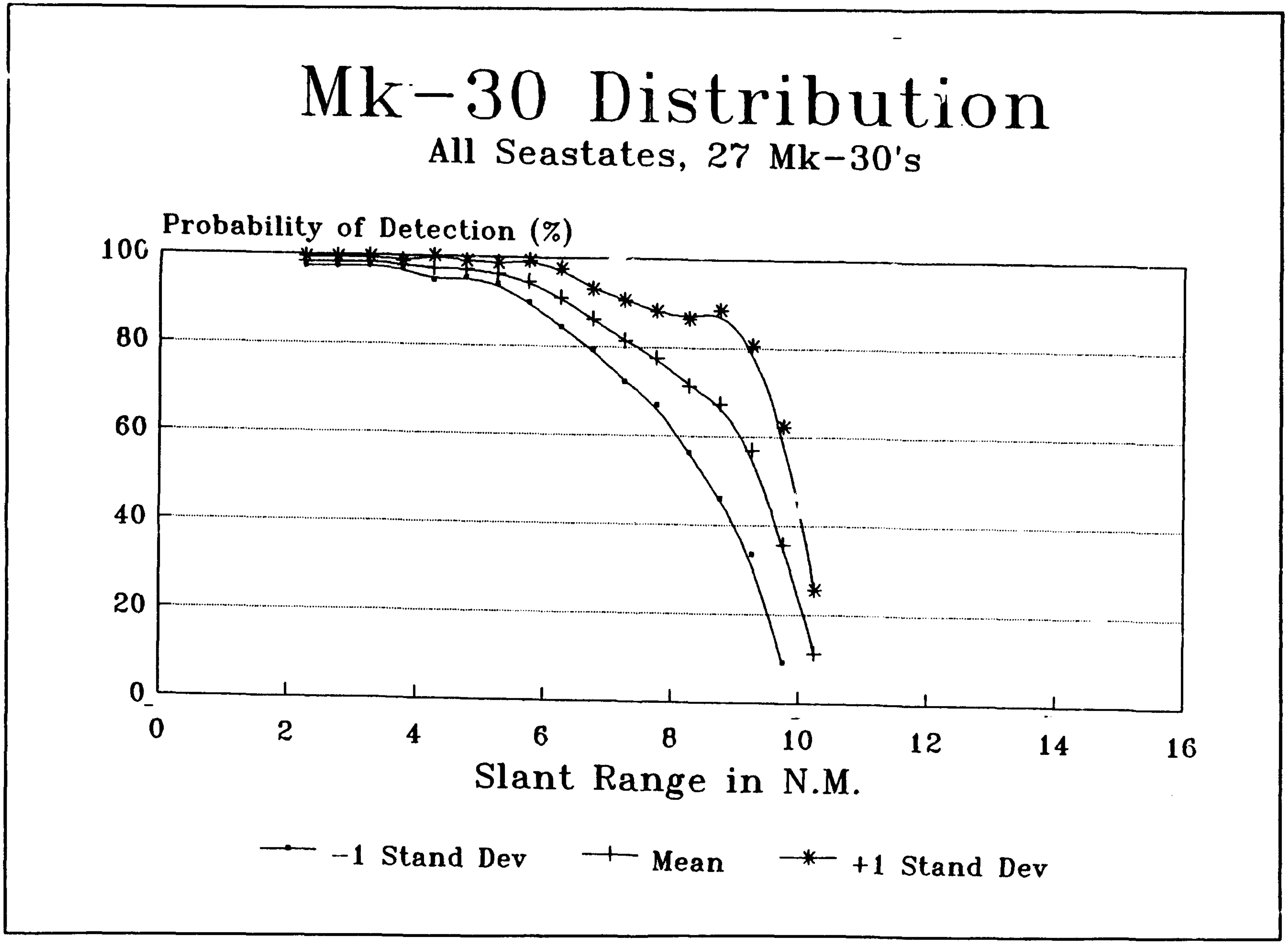

Figure 2. Pingers mounted on 27 MK-30 targets.

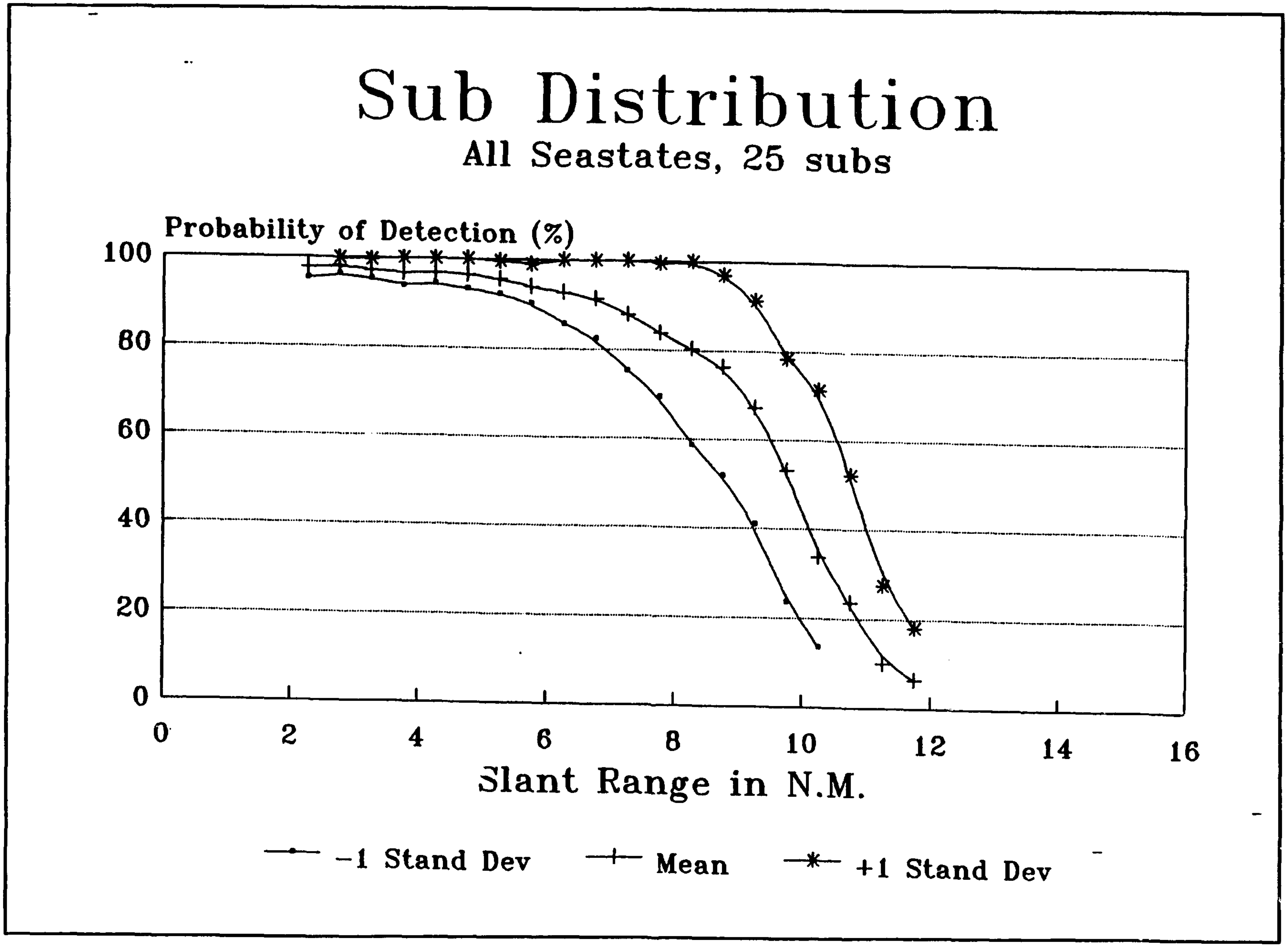

Figure 3. Pingers mounted on 25 submarines.

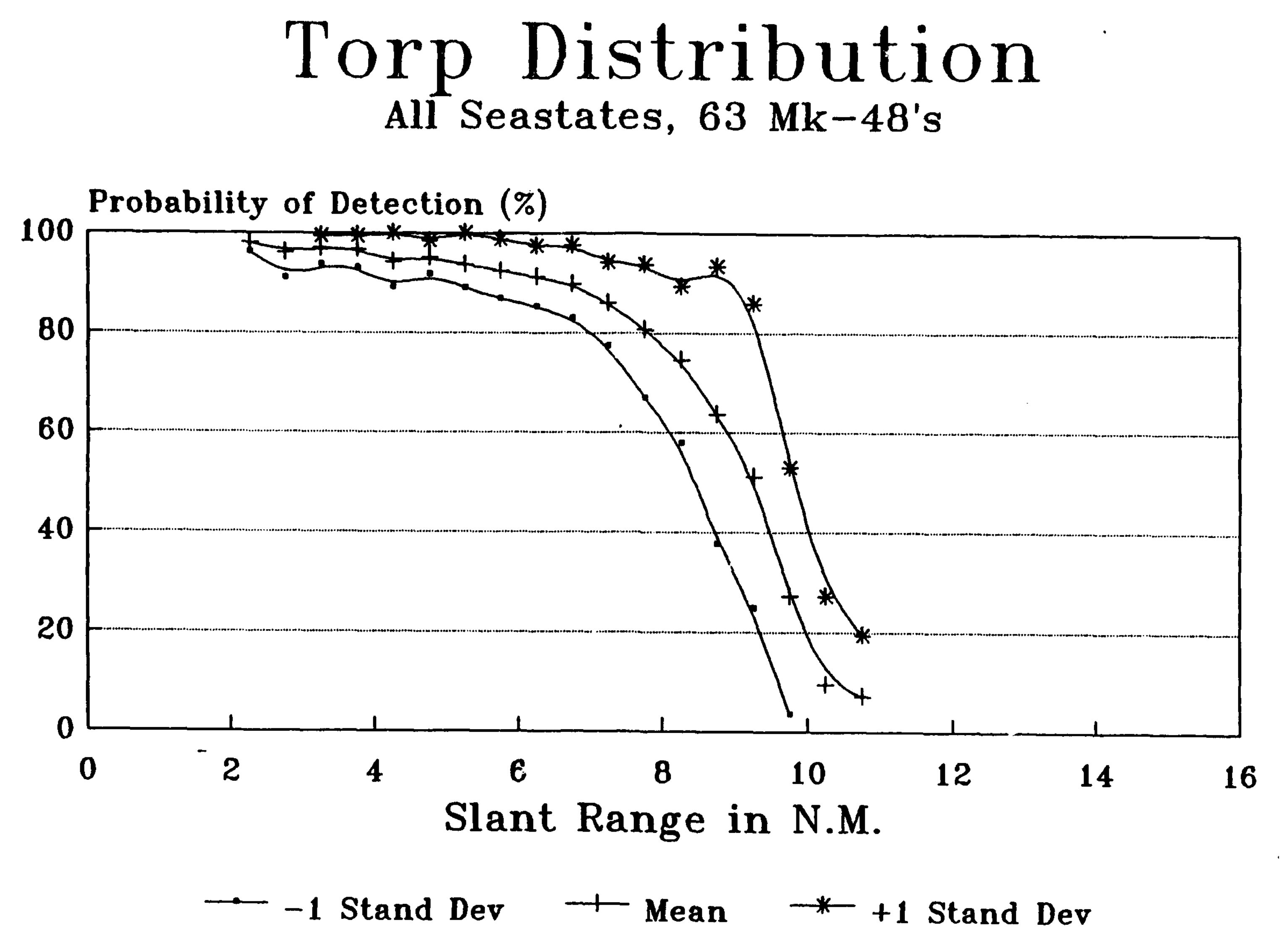

Figure 4. Pingers mounted on 63 MK-48 torpedoes.

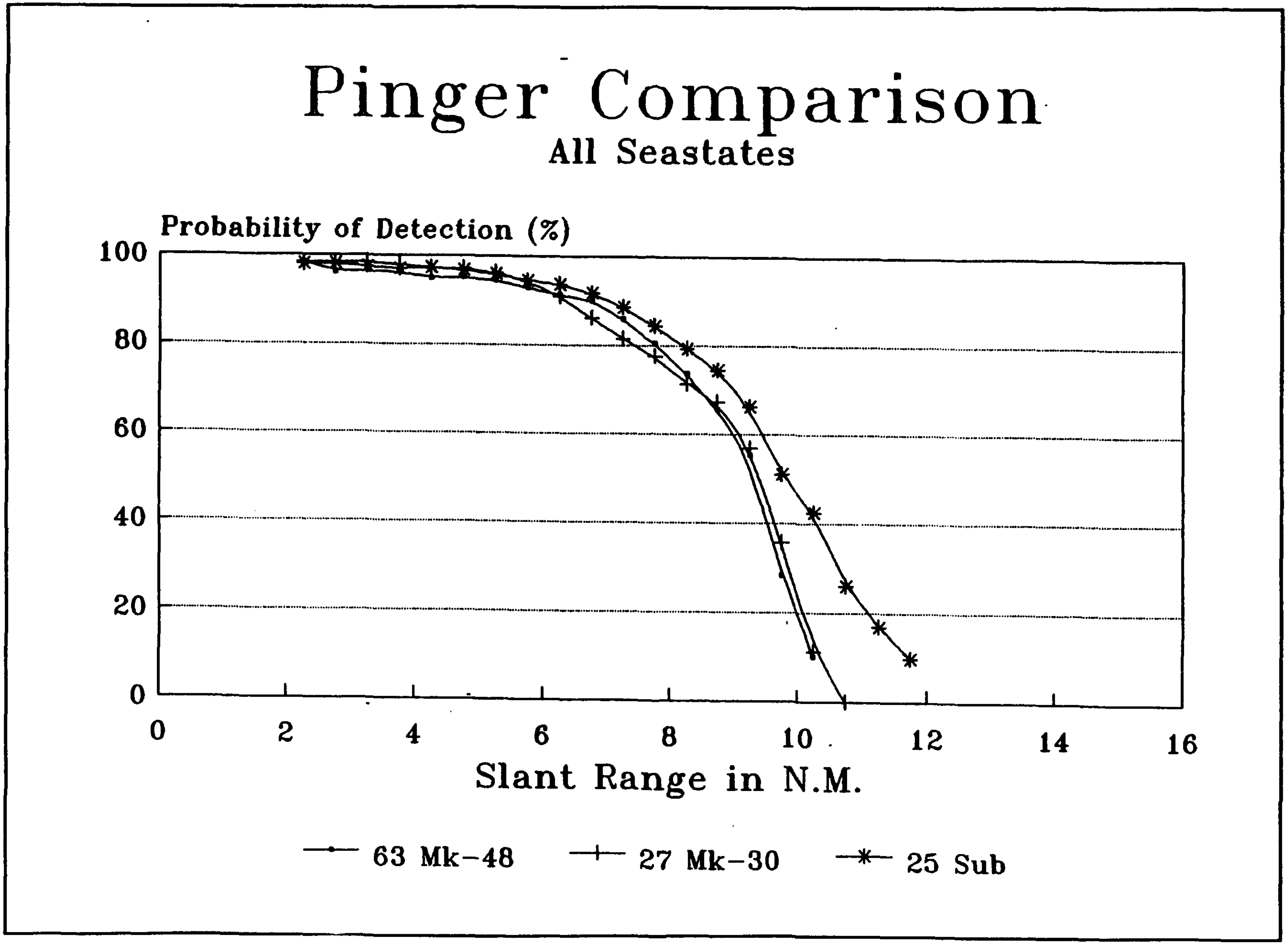

Figure 5. Comparison of pinger mounted on MK-48 torpedos, MK-30 targets, and submarines.

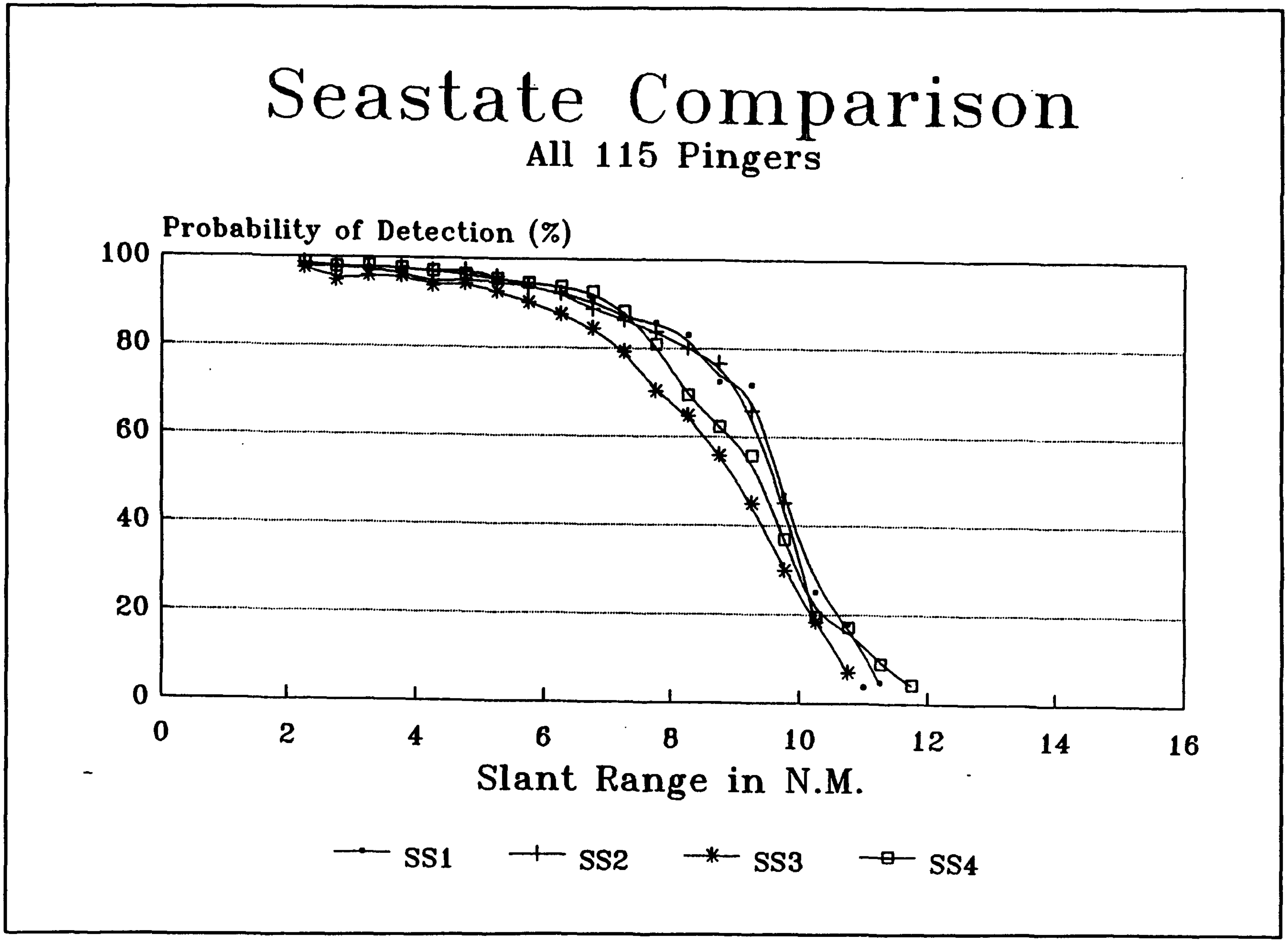

Figure 6. Hearing curves as a function of sea state on all 115 pingers.

DESIGNING A LARGE AREA UNDERWATER RANGE

The hearing probabilities displayed in table I for the grand total can be used to select an optimum hydrophone spacing for a large deep-water range. Initially, it may be tempting to select a hydrophone hearing range based on an acceptable probability (such as 80 percent) and then draw circles of overlapping coverage based on that range. This design concept would not be correct though, because it would ignore the contribution of hydrophones that detect less than 80 percent of the pings. It turns out that these phones can make a significant contribution. The approach taken in this work was to continue thinking in terms of probabilities for determining hydrophone coverage.

A computer program was written which calculates the probability that 'n' hydrophones or more will hear a pinger at a certain location for a proposed range layout. A hexagonal hydrophone distribution was selected with only the distance between phones undefined. For example, a seven hydrophone array will always form a hexagon with one phone in the center, and the underwater range will be made up of many of these identical hexagon building blocks. Hexagon arrays provide very uniform hearing characteristics with well-known properties. Probabilities were only computed for an interior array, which means that it is always surrounded by other hydrophones. For each posit, the software first computes the closest phone, which defines the seven-phone array. Then the probability that each phone in that array will hear the pinger is determined from the slant ranges. Finally the seven probabilities are combined to compute the final result.

Designing a range to track an average pinger is generally not a good approach, because half of the pingers will be weaker and half will be stronger. Assuming a Gaussian distribution, 68 percent of all pingers measured should fall within 1 standard deviation of the mean. Half of the remainder will be stronger and half will be weaker. Therefore, approximately 16 percent of all pingers, or 1 in 6, will exhibit detection probabilities that are worse than a pinger that is one standard deviation down. This probability-of-detection curve was defined as a 'weak' pinger and the mean curve as an 'average' pinger. The program described previously was executed for both types, and the results were printed over a hexagonal hydrophone array so that poor tracking areas could be identified.

Figures 7 through 9 show the performance of a weak pinger with the hydrophone spacing set at 7.5 nautical miles. Notice from figure 8 that 3 or more phones will be hearing in excess of 90 percent all of the time. Three phones minimum are required to generate a hyperbolic solution for an MK-84 pinger. If tracking has already begun and a history of the ping emission times is maintained, two-phone solutions are possible using a spherical

```
99 99 99 99 99 99 99 99 99 99 99100100100100 ●100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
100 99 99 99 99 99 99 99 99 99 99 99100100100100100100100 99 99 99 99 99 99 99 99 99 99 99100
100 99 99 99 99 99 99 99 99 99 99 99 99100100100100100 99 99 99 99 99 99 99 99 99 99 99 99100
100100100 99 99 99 99 99 99 99 99 99 99 99 99100 99 99 99 99 99 99 99 99 99 99 99 99100100100
100100100100 99 99 99 99 99 99 99 99 99 99 99100 99 99 99 99 99 99 99 99 99 99 99100100100100
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
●100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100 ●
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
100100100100 99 99 99 99 99 99 99 99 99 99 99100 99 99 99 99 99 99 99 99 99 99 99100100100100
100100100 99 99 99 99 99 99 99 99 99 99 99 99100 99 99 99 99 99 99 99 99 99 99 99 99100100100
100 99 99 99 99 99 99 99 99 99 99 99 99100100100100100 99 99 99 99 99 99 99 99 99 99 99 99100
100 99 99 99 99 99 99 99 99 99 99 99100100100100100100100 99 99 99 99 99 99 99 99 99 99 99100
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100 ●100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
100 99 99 99 99 99 99 99 99 99 99 99100100100100100100100 99 99 99 99 99 99 99 99 99 99 99100
100 99 99 99 99 99 99 99 99 99 99 99 99100100100100100 99 99 99 99 99 99 99 99 99 99 99 99100
100100100 99 99 99 99 99 99 99 99 99 99 99 99100 99 99 99 99 99 99 99 99 99 99 99 99100100100
100100100100 99 99 99 99 99 99 99 99 99 99 99100 99 99 99 99 99 99 99 99 99 99 99100100100100
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
●100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100 ●
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
100100100100100 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99100100100100100
100100100100 99 99 99 99 99 99 99 99 99 99 99100 99 99 99 99 99 99 99 99 99 99 99100100100100
100100100 99 99 99 99 99 99 99 99 99 99 99 99100 99 99 99 99 99 99 99 99 99 99 99 99100100100
100 99 99 99 99 99 99 99 99 99 99 99 99100100100100100 99 99 99 99 99 99 99 99 99 99 99 99100
100 99 99 99 99 99 99 99 99 99 99 99100100100100100100100 99 99 99 99 99 99 99 99 99 99 99100
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100100100100100100 99 99 99 99 99 99 99 99 99 99 99
99 99 99 99 99 99 99 99 99 99 99100100100100 ●100100100100 99 99 99 99 99 99 99 99 99 99 99
probability 2 or more phones are hearing, weak pinger, 7.5NM spacing
```

Figure 7. Performance of a weak pinger (two or more phones) with hydrophone spacing set at 7.5 nautical miles.

90	90	90	91	91	90	90	90	92	93	94	96	96	97	97	●	97	97	96	96	94	93	92	90	90	90	91	91	90	90	90
90	90	91	91	91	90	91	91	92	93	94	96	96	97	97	97	97	97	96	96	94	93	92	91	91	90	91	91	91	90	90
91	91	91	91	90	91	91	91	92	93	94	95	96	96	97	97	97	96	96	95	94	93	92	91	91	91	90	91	91	91	91
92	92	92	92	90	91	91	91	92	93	94	95	96	96	97	97	97	96	96	95	94	93	92	91	91	91	90	92	92	92	92
93	93	92	92	91	91	91	91	92	93	94	95	95	96	96	96	96	96	95	95	94	93	92	91	91	91	91	92	92	93	93
94	93	93	93	92	92	91	90	91	93	94	95	95	96	96	96	96	96	95	95	94	93	91	90	91	92	92	93	93	93	94
95	94	93	93	92	92	91	90	91	92	94	94	95	96	96	96	96	96	95	94	94	92	91	90	91	92	92	93	93	94	95
95	95	94	94	93	93	91	90	90	92	93	93	94	95	95	95	95	95	94	93	93	92	90	90	91	93	93	94	94	95	95
95	95	95	94	93	93	92	90	90	91	93	93	94	94	95	95	95	94	94	93	93	91	90	90	92	93	93	94	95	95	95
96	96	96	95	94	94	92	91	90	91	92	92	93	93	94	95	94	93	93	92	92	91	90	91	92	94	94	95	96	96	96
96	96	96	95	95	94	93	91	90	91	92	92	93	93	93	94	93	93	93	92	92	91	90	91	93	94	95	95	96	96	96
96	96	96	95	95	94	93	92	91	91	91	91	92	92	93	93	93	92	92	91	91	91	91	92	93	94	95	95	96	96	96
97	97	96	96	95	94	93	92	91	91	91	90	92	92	92	92	92	92	92	90	91	91	91	92	93	94	95	96	96	97	97
97	97	96	96	95	94	93	92	91	91	91	90	91	91	91	91	91	91	91	90	91	91	91	92	93	94	95	96	96	97	97
97	97	97	96	96	94	93	92	91	91	90	91	91	91	90	90	90	91	91	91	90	91	91	92	93	94	96	96	97	97	97
●	97	97	96	96	94	93	92	90	90	90	91	91	90	90	90	90	90	91	91	90	90	90	92	93	94	96	96	97	97	●
97	97	97	96	96	94	93	92	91	91	90	91	91	91	90	90	90	91	91	91	90	91	91	92	93	94	96	96	97	97	97
97	97	96	96	95	94	93	92	91	91	91	90	91	91	91	91	91	91	91	90	91	91	91	92	93	94	95	96	96	97	97
97	97	96	96	95	94	93	92	91	91	91	90	91	92	92	92	92	92	91	90	91	91	91	92	93	94	95	96	96	97	97
96	96	96	95	95	94	93	92	91	91	91	91	92	92	93	93	93	92	92	91	91	91	91	92	93	94	95	95	96	96	96
96	96	96	95	95	94	93	91	90	91	92	92	93	93	93	94	93	93	93	92	92	91	90	91	93	94	95	95	96	96	96
96	96	96	95	94	94	92	91	90	91	92	92	93	93	94	95	94	93	93	92	92	91	90	91	92	94	94	95	96	96	96
95	95	95	94	93	93	92	90	90	91	93	93	94	94	95	95	95	94	94	93	93	91	90	90	92	93	93	94	95	95	95
95	95	94	94	93	93	91	90	90	92	93	93	94	95	95	95	95	95	94	93	93	92	90	90	91	93	93	94	94	95	95
95	94	93	93	92	92	91	90	91	92	94	94	95	96	96	96	96	96	95	94	94	92	91	90	91	92	92	93	93	94	95
94	93	93	93	92	92	91	90	91	93	94	95	95	96	96	96	96	96	95	95	94	93	91	90	91	92	92	93	93	93	94
93	93	92	92	91	91	91	91	92	93	94	95	95	96	96	96	96	96	95	95	94	93	92	91	91	91	91	92	92	93	93
92	92	92	91	90	91	91	91	92	93	94	95	96	96	97	97	97	96	96	95	94	93	92	91	91	91	90	91	92	92	92
91	91	91	91	90	91	91	91	92	93	94	95	96	96	97	97	97	96	96	95	94	93	92	91	91	91	90	91	91	91	91
91	90	91	91	91	90	91	91	92	93	94	96	96	96	97	97	97	96	96	96	94	93	92	91	91	90	91	91	91	90	91
90	90	90	91	91	90	90	90	92	93	94	96	96	97	97	●	97	97	96	96	94	93	92	90	90	90	91	91	90	90	90
91	90	91	91	91	90	91	91	92	93	94	96	96	96	97	97	97	96	96	96	94	93	92	91	91	90	91	91	91	90	91
91	91	91	91	90	91	91	91	92	93	94	95	96	96	97	97	97	96	96	95	94	93	92	91	91	91	90	91	91	91	91
92	92	92	91	90	91	91	91	92	93	94	95	96	96	97	97	97	96	96	95	94	93	92	91	91	91	90	91	92	92	92
93	93	92	92	91	91	91	91	92	93	94	95	95	96	96	96	96	96	95	95	94	93	92	91	91	91	91	92	92	93	93
94	93	93	93	92	92	91	90	91	93	94	95	95	96	96	96	96	96	95	95	94	93	91	90	91	92	92	93	93	93	94
95	94	93	93	92	92	91	90	91	92	94	94	95	96	96	96	96	96	95	94	94	92	91	90	91	92	92	93	93	94	95
95	95	94	94	93	93	91	90	90	92	93	93	94	95	95	95	95	95	94	93	93	92	90	90	91	93	93	94	94	95	95
95	95	95	94	93	93	92	90	90	91	93	93	94	94	95	95	95	94	94	93	93	91	90	90	92	93	93	94	95	95	95
96	96	96	95	94	94	92	91	90	91	92	92	93	93	94	95	94	93	93	92	92	91	90	91	92	94	94	95	96	96	96
96	96	96	95	95	94	93	91	90	91	92	92	93	93	93	94	93	93	93	92	92	91	90	91	93	94	95	95	96	96	96
96	96	96	95	95	94	93	92	91	91	91	91	92	92	93	93	93	92	92	91	91	91	91	92	93	94	95	95	96	96	96
97	97	96	96	95	94	93	92	91	91	91	90	91	92	92	92	92	92	91	90	91	91	91	92	93	94	95	96	96	97	97
97	97	96	96	95	94	93	92	91	91	91	90	91	91	91	91	91	91	91	90	91	91	91	92	93	94	95	96	96	97	97
97	97	97	96	96	94	93	92	91	91	90	91	91	91	90	90	90	91	91	91	90	91	91	92	93	94	96	96	97	97	97
●	97	97	96	96	94	93	92	90	90	90	91	91	90	90	90	90	90	91	91	90	90	90	92	93	94	96	96	97	97	●
97	97	97	96	96	94	93	92	91	91	90	91	91	91	90	90	90	91	91	91	90	91	91	92	93	94	96	96	97	97	97
97	97	96	96	95	94	93	92	91	91	91	90	91	91	91	91	91	91	91	90	91	91	91	92	93	94	95	96	96	97	97
97	97	96	96	95	94	93	92	91	91	91	90	92	92	92	92	92	92	92	90	91	91	91	92	93	94	95	96	96	97	97
96	96	96	95	95	94	93	92	91	91	91	91	92	92	93	93	93	92	92	91	91	91	91	92	93	94	95	95	96	96	96
96	96	96	95	95	94	93	91	90	91	92	92	93	93	93	94	93	93	93	92	92	91	90	91	93	94	95	95	96	96	96
96	96	96	95	94	94	92	91	90	91	92	92	93	93	94	95	94	93	93	92	92	91	90	91	92	94	94	95	96	96	96
95	95	95	94	93	93	92	90	90	91	93	93	94	94	95	95	95	94	94	93	93	91	90	90	92	93	93	94	95	95	95
95	95	94	94	93	93	91	90	90	92	93	93	94	95	95	95	95	95	94	93	93	92	90	90	91	93	93	94	94	95	95
95	94	93	93	92	92	91	90	91	92	94	94	95	96	96	96	96	96	95	94	94	92	91	90	91	92	92	93	93	94	95
94	93	93	93	92	92	91	90	91	93	94	95	95	96	96	96	96	96	95	95	94	93	91	90	91	92	92	93	93	93	94
93	93	92	92	91	91	91	91	92	93	94	95	95	96	96	96	96	96	95	95	94	93	92	91	91	91	91	92	92	93	93
92	92	92	92	90	91	91	91	92	93	94	95	96	96	97	97	97	96	96	95	94	93	92	91	91	91	90	92	92	92	92
91	91	91	91	90	91	91	91	92	93	94	95	96	96	97	97	97	96	96	95	94	93	92	91	91	91	90	91	91	91	91
90	90	91	91	91	90	91	91	92	93	94	96	96	97	97	97	97	97	96	96	94	93	92	91	91	90	91	91	91	90	90
90	90	90	91	91	90	90	90	92	93	94	96	96	97	97	●	97	97	96	96	94	93	92	90	90	90	91	91	90	90	90

probability 3 or more phones are hearing, weak pinger, 7.5NM spacing

Figure 8. Performance of a weak pinger (three or more phones) with hydrophone spacing set at 7.5 nautical miles.

52	54	54	55	53	49	53	56	62	67	72	79	82	84	87	●	87	84	82	79	72	67	62	56	53	49	53	55	54	54	52
55	55	57	58	54	51	54	57	62	66	72	79	82	84	86	87	86	84	82	79	72	66	62	57	54	51	54	58	57	55	55
58	59	60	59	55	54	56	59	61	65	71	78	81	83	85	86	85	83	81	78	71	65	61	59	56	54	55	59	60	59	58
62	63	62	60	56	57	55	59	62	66	71	76	80	83	84	85	84	83	80	76	71	66	62	59	55	57	56	60	62	63	62
66	66	64	62	59	59	56	57	61	66	71	75	79	82	83	83	83	82	79	75	71	66	61	57	56	59	59	62	64	66	66
70	68	65	64	62	60	57	54	59	64	70	74	78	81	82	82	82	81	78	74	70	64	59	54	57	60	62	64	65	68	70
73	71	68	67	63	62	57	54	57	62	68	71	75	79	80	80	80	79	75	71	68	62	57	54	57	62	63	67	68	71	73
75	74	72	69	65	64	59	54	55	60	66	67	72	76	78	77	78	76	72	67	66	60	55	54	59	64	65	69	72	74	75
77	77	76	72	67	66	60	55	54	59	64	65	70	72	74	75	74	72	70	65	64	59	54	55	60	66	67	72	76	77	77
80	80	79	75	71	68	62	57	53	57	62	63	67	68	71	73	71	68	67	63	62	57	53	57	62	68	71	75	79	80	80
82	82	81	77	74	70	64	58	54	57	60	62	64	65	68	70	68	65	64	62	60	57	54	58	64	70	74	77	81	82	82
83	83	82	79	75	71	66	60	57	56	59	59	62	64	66	66	66	64	62	59	59	56	57	60	66	71	75	79	82	83	83
85	84	83	80	76	71	66	62	59	55	57	57	60	62	63	62	63	62	60	57	57	55	59	62	66	71	76	80	83	84	85
86	85	83	81	77	71	65	61	59	56	54	55	59	60	59	58	59	60	59	55	54	56	59	61	65	71	77	81	83	85	86
87	86	84	82	79	72	66	62	57	54	51	54	58	57	55	55	55	57	58	54	51	54	57	62	66	72	79	82	84	86	87
●	86	84	82	79	72	67	62	56	53	49	53	55	54	54	53	54	54	55	53	49	53	56	62	67	72	79	82	84	86	●
87	86	84	82	79	72	66	62	57	54	51	54	58	57	55	55	55	57	58	54	51	54	57	62	66	72	79	82	84	86	87
86	85	83	81	77	71	65	61	59	56	54	55	59	60	58	58	58	60	59	55	54	56	59	61	65	71	77	81	83	85	86
85	84	83	80	76	71	66	61	59	55	57	56	60	62	62	62	62	62	60	56	57	55	59	61	66	71	76	80	83	84	85
83	83	82	79	75	71	66	61	57	56	59	59	62	63	66	66	66	63	62	59	59	56	57	61	66	71	75	79	82	83	83
82	82	81	77	74	70	64	58	54	57	60	62	64	65	68	70	68	65	64	62	60	57	54	58	64	70	74	77	81	82	82
80	80	79	75	71	68	62	57	53	57	61	63	67	68	71	73	71	68	67	63	61	57	53	57	62	68	71	75	79	80	80
77	78	76	72	67	66	60	55	54	58	64	65	69	72	74	75	74	72	69	65	64	58	54	55	60	66	67	72	76	78	77
75	74	72	69	65	64	59	54	55	60	66	67	72	76	77	77	77	76	72	67	66	60	55	54	59	64	65	69	72	74	75
73	71	68	67	63	62	57	54	57	62	68	71	75	79	80	80	80	79	75	71	68	62	57	54	57	62	63	67	68	71	73
70	68	65	64	62	60	57	54	59	64	70	74	77	81	82	82	82	81	77	74	70	64	59	54	57	60	62	64	65	68	70
66	66	63	62	59	59	56	57	61	66	71	75	78	82	83	83	83	82	78	75	71	66	61	57	56	59	59	62	63	66	66
62	63	62	60	56	57	55	59	62	66	71	76	80	83	84	85	84	83	80	76	71	66	62	59	55	57	56	60	62	63	62
58	59	60	59	55	54	56	59	61	65	71	77	81	83	85	86	85	83	81	77	71	65	61	59	56	54	55	59	60	59	58
55	55	57	58	54	51	54	57	62	66	72	79	82	84	86	87	86	84	82	79	72	66	62	57	54	51	54	58	57	55	55
53	54	54	55	53	49	53	56	62	67	72	79	82	84	86	●	86	84	82	79	72	67	62	56	53	49	53	55	54	54	53
55	55	57	58	54	51	54	57	62	66	72	79	82	84	86	87	86	84	82	79	72	66	62	57	54	51	54	58	57	55	55
58	59	60	59	55	54	56	59	61	65	71	77	81	83	85	86	85	83	81	77	71	65	61	59	56	54	55	59	60	59	58
62	63	62	60	56	57	55	59	62	66	71	76	80	83	84	85	84	83	80	76	71	66	62	59	55	57	56	60	62	63	62
66	66	63	62	59	59	56	57	61	66	71	75	78	82	83	83	83	82	78	75	71	66	61	57	56	59	59	62	63	66	66
70	68	65	64	62	60	57	54	59	64	70	74	77	81	82	82	82	81	77	74	70	64	59	54	57	60	62	64	65	68	70
73	71	68	67	63	62	57	54	57	62	68	71	75	79	80	80	80	79	75	71	68	62	57	54	57	62	63	67	68	71	73
75	74	72	69	65	64	59	54	55	60	66	67	72	76	77	77	77	76	72	67	66	60	55	54	59	64	65	69	72	74	75
77	78	76	72	67	66	60	55	54	58	64	65	69	72	74	75	74	72	69	65	64	58	54	55	60	66	67	72	76	78	77
80	80	79	75	71	68	62	57	53	57	61	63	67	68	71	73	71	68	67	63	61	57	53	57	62	63	71	75	79	80	80
82	82	81	77	74	70	64	58	54	57	60	62	64	65	68	70	68	65	64	62	60	57	54	58	64	70	74	77	81	82	82
83	83	82	79	75	71	66	61	57	56	59	59	62	63	66	66	66	63	62	59	59	56	57	61	66	71	75	79	82	83	83
85	84	83	80	76	71	66	61	59	55	57	56	60	62	62	62	62	62	60	56	57	55	59	61	66	71	76	80	83	84	85
86	85	83	81	77	71	65	61	59	56	54	55	59	60	58	58	58	60	59	55	54	56	59	61	65	71	77	81	83	85	86
87	86	84	82	79	72	66	62	57	54	51	54	58	57	55	55	55	57	58	54	51	54	57	62	66	72	79	82	84	86	87
●	86	84	82	79	72	67	62	56	53	49	53	55	54	54	52	54	54	55	53	49	53	56	62	67	72	79	82	84	86	●
87	86	84	82	79	72	66	62	57	54	51	54	58	57	55	55	55	57	58	54	51	54	57	62	66	72	79	82	84	86	87
86	85	83	81	77	71	65	61	59	56	54	55	59	60	59	58	59	60	59	55	54	56	59	61	65	71	77	81	83	85	86
85	84	83	80	76	71	66	62	59	55	57	57	60	62	63	62	63	62	60	57	57	55	59	62	66	71	76	80	83	84	85
83	83	82	79	75	71	66	60	57	56	59	59	62	64	66	66	66	64	62	59	59	56	57	60	66	71	75	79	82	83	83
82	82	81	77	74	70	64	58	54	57	60	62	64	65	68	70	68	65	64	62	60	57	54	58	64	70	74	77	81	82	82
80	80	79	75	71	68	62	57	53	57	62	63	67	68	71	73	71	68	67	63	62	57	53	57	62	68	71	75	79	80	80
77	77	76	72	67	66	60	55	54	59	64	65	70	72	74	75	74	72	70	65	64	59	54	55	60	66	67	72	76	77	77
75	74	72	69	65	64	59	54	55	60	66	67	72	76	78	77	78	76	72	67	66	60	55	54	59	64	65	69	72	74	75
73	71	68	67	63	62	57	54	57	62	68	71	75	79	80	80	80	79	75	71	68	62	57	54	57	62	63	67	68	71	73
70	68	65	64	62	60	57	54	59	64	70	74	78	81	82	82	82	81	78	74	70	64	59	54	57	60	62	64	65	68	70
66	66	64	62	59	59	56	57	61	66	71	75	79	82	83	83	83	82	79	75	71	66	61	57	56	59	59	62	64	66	66
62	63	62	60	56	57	55	59	62	66	71	76	80	83	84	85	84	83	80	76	71	66	62	59	55	57	56	60	62	63	62
58	59	60	59	55	54	56	59	61	65	71	78	81	83	85	86	85	83	81	78	71	65	61	59	56	54	55	59	60	59	58
55	55	57	58	54	51	54	57	62	66	72	79	82	84	86	87	86	84	82	79	72	66	62	57	54	51	54	58	57	55	55
52	54	54	55	53	49	53	56	62	67	72	79	82	84	87	●	87	84	82	79	72	67	62	56	53	49	53	55	54	54	52

probability 4 or more phones are hearing, weak pinger, 7.5NM spacing

Figure 9. Performance of a weak pinger (four or more phones) with hydrophone spacing set at 7.5 nautical miles.

algorithm. Figure 7 shows that spherical solutions can be generated 99 to 100 percent of the time. Even a four hydrophone hyperbolic least squares solution, generally considered the most accurate, is available over 50 percent of the time in the worst case.

Detection probabilities for an average pinger are plotted in figures 10 through 12 and demonstrate much better tracking characteristics. Three-phone solutions will be available over 98 percent of the time, while four-phone solutions can be made for about 9 pings out of every 10. It is interesting to see how far the hydrophone spacing can be extended if a range were designed around an average pinger instead of a weak one. Figures 13 through 15 show a layout with 9.0 nautical mile spacing between phones. Three-phone solutions are available 90 percent of the time so that an occasional two-phone fix would be required.

An important concern for any underwater range is how the hydrophone coverage degrades in the event that a phone fails. Figures 16 through 18 demonstrate how probabilities are affected by the failure of the center phone for a 7.5 nautical mile layout. Only a weak pinger is shown. A surprising result is that the area of poorest track is not directly above the failed phone, but actually shows up between the dead phone and its neighbor. If the phone spacing is increased far enough though, a tracking "hole" will develop directly above the dead phone. Notice that tracking a weak pinger throughout the entire area should still be possible, although there will be more reliance on two-phone solutions.

VERIFICATION OF THEORETICAL COVERAGE

The theoretical coverage provided by a hydrophone spacing of 7.5 nautical miles should satisfy most range tracking requirements in a conservative fashion. Even if a hydrophone dies or an exceptionally weak pinger shows up on the range, it should be possible to acquire and maintain solid track. But are there any potential problems that have been overlooked?

Once again, the BSURE hydrophones can be used to verify the theoretical conclusions. The Twelve Target Tracking System has 12 trackers available to an operator. In normal situations, each tracker will be assigned a different target code to "listen to" and provide position data. Because each target code is a unique phase-coded identification, the system can track up to 12 underwater targets simultaneously. The tracker normally assigns the seven closest hydrophones for detecting ping arrival times to the signal processor. As the target moves around the range, the

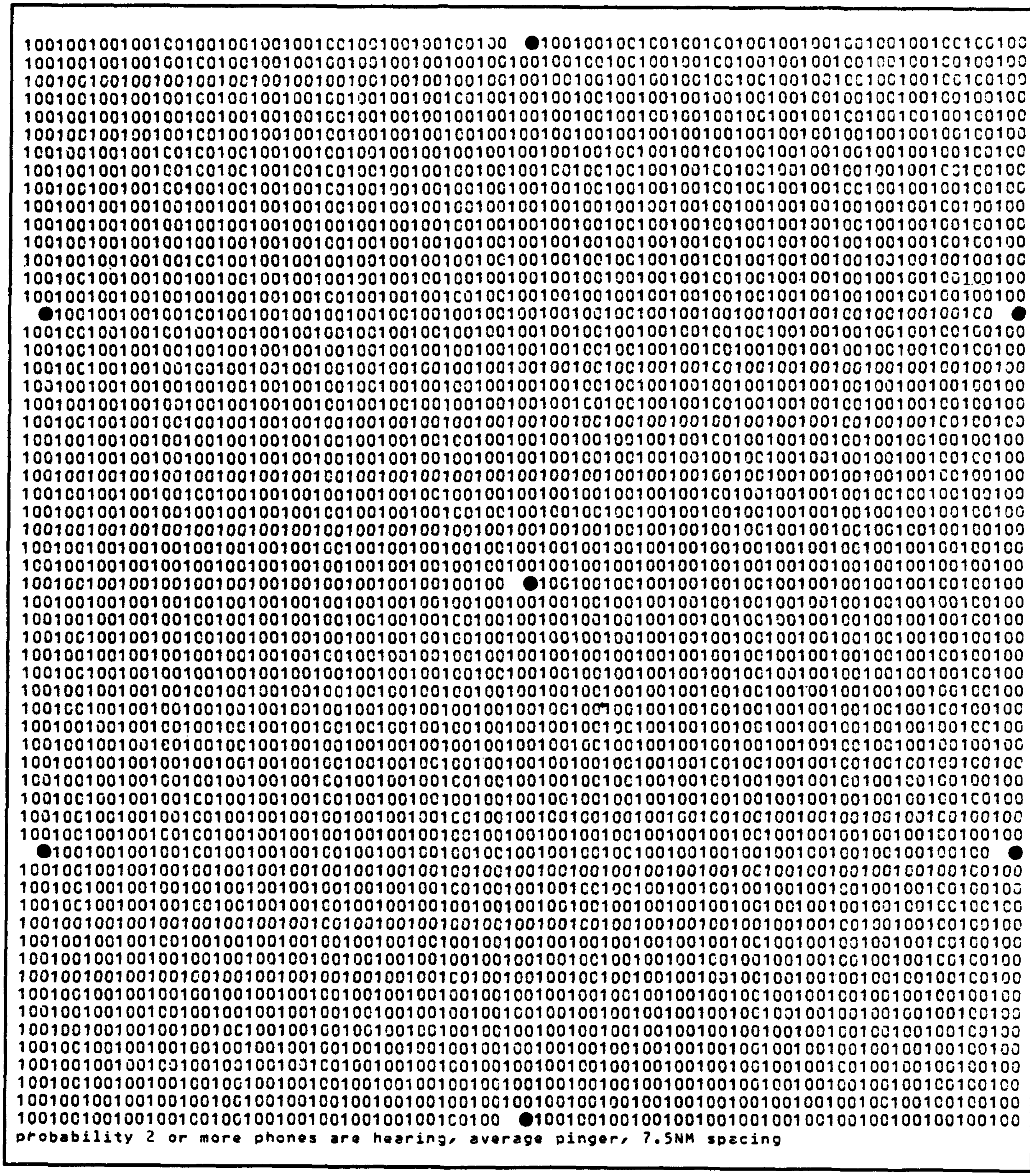

Figure 10. Performance of an average pinger (two or more phones) with hydrophone spacing set at 7.5 nautical miles.

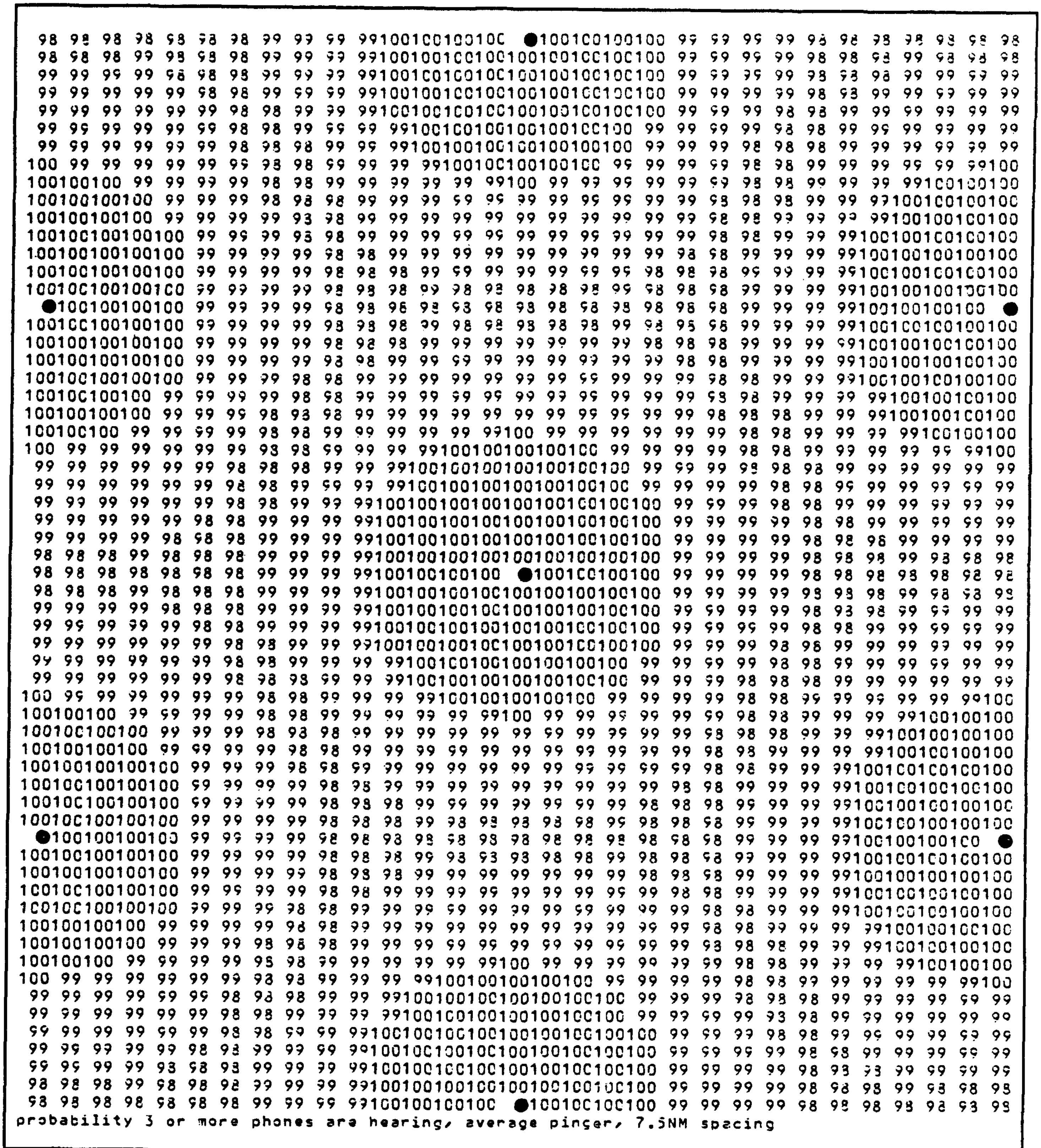

Figure 11. Performance of an average pinger (three or more phones) with hydrophone spacing set at 7.5 nautical miles.

82	83	83	84	84	83	84	87	90	92	94	96	97	97	98	●	98	97	97	96	94	92	90	87	84	83	84	84	83	83	82
84	84	85	86	85	84	85	87	90	92	94	96	97	97	98	98	98	97	97	96	94	92	90	87	85	84	85	86	85	84	84
87	87	88	87	86	84	85	87	89	92	94	96	97	97	98	98	98	97	97	96	94	92	89	87	85	84	86	87	88	87	87
90	90	89	88	87	86	84	87	89	92	94	96	97	97	97	98	97	97	97	96	94	92	89	87	84	86	87	88	89	90	90
92	92	90	90	88	87	85	85	88	92	94	95	96	97	97	97	97	97	96	95	94	92	88	85	85	87	88	90	90	92	92
93	93	92	90	90	88	85	84	87	91	93	95	96	97	97	97	97	97	96	95	93	91	87	84	85	88	90	90	92	93	93
95	94	93	92	90	89	86	83	86	90	93	94	95	96	97	97	97	96	95	94	93	90	86	83	86	89	90	92	93	94	95
95	95	94	93	92	90	87	83	84	88	92	93	94	95	96	96	96	95	94	93	92	88	84	83	87	90	92	93	94	95	95
96	96	95	94	93	92	88	84	83	87	90	92	93	94	95	95	95	94	93	92	90	87	83	84	88	92	93	94	95	96	96
97	97	96	95	94	93	90	86	82	86	89	90	92	93	94	95	94	93	92	90	89	86	82	86	90	93	94	95	96	97	97
97	97	97	96	95	93	91	87	84	85	88	90	90	92	93	93	93	92	90	90	88	85	84	87	91	93	95	96	97	97	97
97	97	97	96	95	94	92	88	85	85	87	89	90	90	92	92	92	90	90	89	87	85	85	88	92	94	95	96	97	97	97
98	97	97	97	96	94	92	89	87	84	86	87	88	89	90	90	90	89	88	87	86	84	87	89	92	94	96	97	97	97	98
98	98	97	97	96	94	92	89	87	85	85	86	87	88	87	87	87	88	87	86	85	85	87	89	92	94	96	97	97	98	98
98	98	97	97	96	94	91	90	87	84	84	85	86	85	84	84	84	85	86	85	84	84	87	90	91	94	96	97	97	98	98
●	98	97	97	96	94	92	89	87	84	83	84	84	83	83	82	83	83	84	84	83	84	87	89	92	94	96	97	97	98	●
98	98	97	97	96	94	92	90	87	84	84	84	86	85	84	84	84	85	86	84	84	84	87	90	92	94	96	97	97	98	98
98	98	97	97	96	94	92	89	87	85	84	86	87	88	87	87	87	88	87	86	84	85	87	89	92	94	96	97	97	98	98
98	97	97	97	96	94	92	89	87	84	86	87	88	89	90	90	90	89	88	87	86	84	87	89	92	94	96	97	97	97	98
97	97	97	96	95	94	92	88	85	85	87	88	89	90	92	92	92	90	89	88	87	85	85	88	92	94	95	96	97	97	97
97	97	97	96	95	93	91	87	84	85	88	89	90	92	93	93	93	92	90	89	88	85	84	87	91	93	95	96	97	97	97
97	97	96	95	94	93	90	86	82	86	89	90	92	93	94	95	94	93	92	90	89	86	82	86	90	93	94	95	96	97	97
96	96	95	94	93	92	88	84	83	87	90	92	93	94	95	95	95	94	93	92	90	87	83	84	88	92	93	94	95	96	96
95	95	94	93	92	90	87	83	84	88	92	93	94	95	96	96	96	95	94	93	92	88	84	83	87	90	92	93	94	95	95
95	94	93	92	90	89	86	83	86	90	93	94	95	96	97	97	97	96	95	94	93	90	86	83	86	89	90	92	93	94	95
93	93	92	90	90	88	85	84	87	91	93	95	96	97	97	97	97	97	96	95	93	91	87	84	85	88	90	90	92	93	93
92	92	90	90	88	87	85	85	88	92	94	95	96	97	97	97	97	97	96	95	94	92	88	85	85	87	88	90	90	92	92
90	90	89	88	87	86	84	87	89	92	94	96	97	97	97	98	97	97	97	96	94	92	89	87	84	86	87	88	89	90	90
87	87	88	87	86	85	85	87	89	92	94	96	97	97	98	98	98	97	97	96	94	92	89	87	85	85	86	87	88	87	87
84	84	85	86	85	84	85	87	90	91	94	96	97	97	98	98	98	97	97	96	94	91	90	87	85	84	85	86	85	84	84
82	83	83	84	84	83	84	87	90	92	94	96	97	97	98	●	98	97	97	96	94	92	90	87	84	83	84	84	83	83	82
84	84	85	86	85	84	85	87	90	91	94	96	97	97	98	98	98	97	97	96	94	91	90	87	85	84	85	86	85	84	84
87	87	88	87	86	85	85	87	89	92	94	96	97	97	98	98	98	97	97	96	94	92	89	87	85	85	86	87	88	87	87
90	90	89	88	87	86	84	87	89	92	94	96	97	97	97	98	97	97	97	96	94	92	89	87	84	86	87	88	89	90	90
92	92	90	90	88	87	85	85	88	92	94	95	96	97	97	97	97	97	96	95	94	92	88	85	85	87	88	90	90	92	92
93	93	92	90	90	88	85	84	87	91	93	95	96	97	97	97	97	97	96	95	93	91	87	84	85	88	90	90	92	93	93
95	94	93	92	90	89	86	83	86	90	93	94	95	96	97	97	97	96	95	94	93	90	86	83	86	89	90	92	93	94	95
95	95	94	93	92	90	87	83	84	88	92	93	94	95	96	96	96	95	94	93	92	88	84	83	87	90	92	93	94	95	95
96	96	95	94	93	92	88	84	83	87	90	92	93	94	95	95	95	94	93	92	90	87	83	84	88	92	93	94	95	96	96
97	97	96	95	94	93	90	86	82	86	89	90	92	93	94	95	94	93	92	90	89	86	82	86	90	93	94	95	96	97	97
97	97	97	96	95	93	91	87	84	85	88	89	90	92	93	93	93	92	90	89	88	85	84	87	91	93	95	96	97	97	97
97	97	97	96	95	94	92	88	85	85	87	88	89	90	92	92	92	90	89	88	87	85	85	88	92	94	95	96	97	97	97
98	97	97	97	96	94	92	89	87	84	86	87	88	89	90	90	90	89	88	87	86	84	87	89	92	94	96	97	97	97	98
98	98	97	97	96	94	92	89	87	85	84	86	87	88	87	87	87	88	87	86	84	85	87	89	92	94	96	97	97	98	98
98	98	97	97	96	94	92	90	87	84	84	84	86	85	84	84	84	85	86	84	84	84	87	90	92	94	96	97	97	98	98
●	98	97	97	96	94	92	89	87	84	83	84	84	83	82	81	82	83	84	84	83	84	87	89	92	94	96	97	97	98	●
98	98	97	97	96	94	91	90	87	84	84	85	86	85	84	84	84	85	86	85	84	84	87	90	91	94	96	97	97	98	98
98	98	97	97	96	94	92	89	87	85	85	86	87	88	87	87	87	88	87	86	85	85	87	89	92	94	96	97	97	98	98
98	97	97	97	96	94	92	89	87	84	86	87	88	89	90	90	90	89	88	87	86	84	87	89	92	94	96	97	97	97	98
97	97	97	96	95	94	92	88	85	85	87	89	90	90	92	92	92	90	90	89	87	85	85	88	92	94	95	96	97	97	97
97	97	97	96	95	93	91	87	84	85	88	90	90	92	93	93	93	92	90	90	88	85	84	87	91	93	95	96	97	97	97
97	97	96	95	94	93	90	86	82	86	89	90	92	93	94	95	94	93	92	90	89	86	82	86	90	93	94	95	96	97	97
96	96	95	94	93	92	88	84	83	87	90	92	93	94	95	95	95	94	93	92	90	87	83	84	88	92	93	94	95	96	96
95	95	94	93	92	90	87	83	84	88	92	93	94	95	96	96	96	95	94	93	92	88	84	83	87	90	92	93	94	95	95
95	94	93	92	90	89	86	83	86	90	93	94	95	96	97	97	97	96	95	94	93	90	86	83	86	89	90	92	93	94	95
93	93	92	90	90	88	85	84	87	91	93	95	96	97	97	97	97	97	96	95	93	91	87	84	85	88	90	90	92	93	93
92	92	90	90	88	87	85	85	88	92	94	95	96	97	97	97	97	97	96	95	94	92	88	85	85	87	88	90	90	92	92
90	90	89	88	87	86	84	87	89	92	94	96	97	97	97	98	97	97	97	96	94	92	89	87	84	86	87	88	89	90	90
87	87	88	87	86	84	85	87	89	92	94	96	97	97	98	98	98	97	97	96	94	92	89	87	85	84	86	87	88	87	87
84	84	85	86	85	84	85	87	90	92	94	96	97	97	98	98	98	97	97	96	94	92	90	87	85	84	85	86	85	84	84
82	83	83	84	84	83	84	87	90	92	94	96	97	97	98	●	98	97	97	96	94	92	90	87	84	83	84	84	83	83	82

probability 4 or more phones are hearing, average pinger, 7.5NM spacing

Figure 12. Performance of an average pinger (four or more phones) with hydrophone spacing set at 7.5 nautical miles.

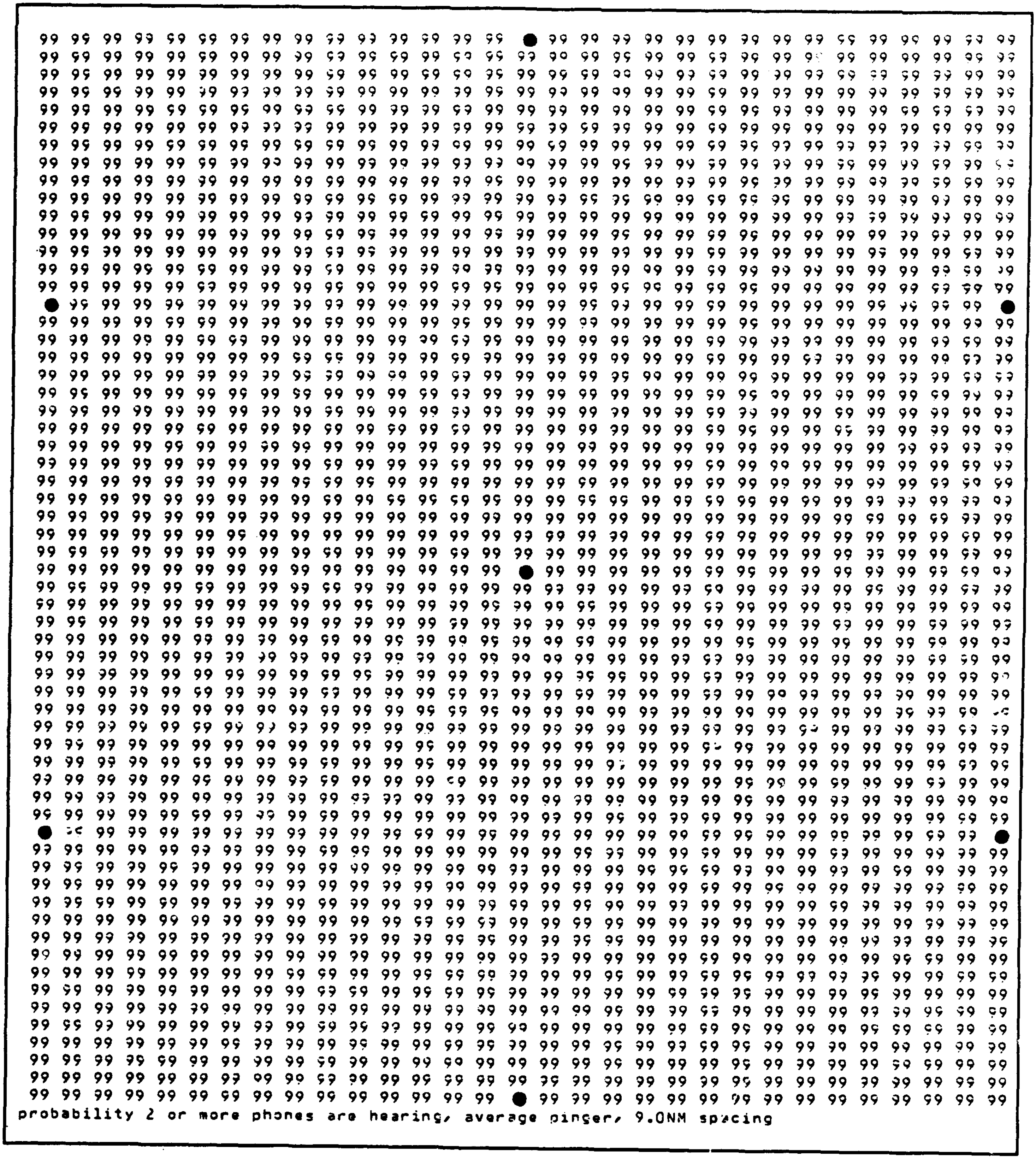

Figure 13. Hydrophone layout of an average pinger (two or more phones) with spacing set at 9 nautical miles.

91	91	91	88	86	86	87	87	88	89	90	90	90	90	92	●	92	90	90	90	90	89	88	87	87	86	86	88	91	91	91
91	91	90	89	87	86	87	88	88	89	90	90	90	90	92	93	92	90	90	90	90	89	88	88	87	86	87	89	90	91	91
91	91	91	89	87	87	88	89	89	90	90	90	89	90	91	92	91	90	89	90	90	90	89	89	88	87	87	89	91	91	91
91	90	90	89	87	88	88	90	90	90	90	90	89	89	90	90	90	89	89	90	90	90	90	90	88	88	87	89	90	90	91
90	90	90	88	87	89	90	90	90	90	90	90	89	90	90	90	90	90	89	90	90	90	90	90	90	89	87	88	90	90	90
90	90	90	88	88	90	90	91	91	90	90	90	90	90	90	89	90	90	90	90	90	90	91	91	90	90	88	88	90	90	90
91	90	90	89	89	90	90	91	91	91	90	90	90	90	90	89	90	90	90	90	90	91	91	91	90	90	89	89	90	90	91
90	90	90	90	90	90	91	91	91	91	90	90	90	90	90	89	90	90	90	90	90	91	91	91	91	90	90	90	90	90	90
89	90	90	90	90	90	91	91	91	91	90	90	90	90	90	90	90	90	90	90	90	91	91	91	91	90	90	90	90	90	89
89	90	90	90	90	90	91	91	91	90	90	89	89	90	90	91	90	90	89	89	90	90	91	91	91	90	90	90	90	90	89
89	90	90	90	90	90	90	91	91	90	90	86	88	90	90	90	90	90	88	88	90	90	91	91	90	90	90	90	90	90	89
90	90	90	89	90	90	90	90	90	90	89	87	88	90	90	90	90	90	88	87	89	90	90	90	90	90	90	89	90	90	90
90	90	89	89	90	90	90	90	90	88	88	87	89	90	90	91	90	90	89	87	88	88	90	90	90	90	90	89	89	90	90
92	91	90	89	90	90	90	89	89	88	87	87	89	91	91	91	91	91	89	87	87	88	89	89	90	90	90	89	90	91	92
93	91	90	90	90	90	89	88	88	87	86	87	89	90	91	91	91	90	89	87	86	87	88	88	89	90	90	90	90	91	93
●	92	90	90	90	90	89	88	87	87	86	86	88	91	91	91	91	91	88	86	86	87	87	88	89	90	90	90	90	92	●
93	92	90	90	90	90	89	88	88	87	86	87	89	90	91	91	91	90	89	87	86	87	88	88	89	90	90	90	90	92	93
92	91	90	89	90	90	90	89	89	87	87	87	89	91	91	91	91	91	89	87	87	87	89	89	90	90	90	89	90	91	92
90	90	89	89	90	90	90	90	90	88	88	87	89	90	90	91	90	90	89	87	88	88	90	90	90	90	90	89	89	90	90
90	90	90	89	90	90	90	90	90	89	89	87	88	90	90	90	90	90	88	87	89	89	90	90	90	90	90	89	90	90	90
89	90	90	90	90	90	90	91	91	90	90	88	88	90	90	90	90	90	88	88	90	90	91	91	90	90	90	90	90	90	89
89	90	90	90	90	90	91	91	91	90	90	89	89	90	90	90	90	90	89	89	90	90	91	91	91	90	90	90	90	90	89
89	90	90	90	90	90	91	91	91	91	90	90	90	90	90	90	90	90	90	90	90	91	91	91	91	90	90	90	90	90	89
90	90	90	90	90	90	91	91	91	91	90	90	90	90	90	89	90	90	90	90	90	91	91	91	91	90	90	90	90	90	90
90	90	90	89	89	90	90	91	91	91	90	90	90	90	90	89	90	90	90	90	90	91	91	91	90	90	89	89	90	90	90
90	90	90	88	88	90	90	91	91	90	90	90	90	90	90	89	90	90	90	90	90	90	91	91	90	90	88	88	90	90	90
90	90	90	88	87	89	90	90	90	90	90	90	89	90	90	90	90	90	89	90	90	90	90	90	90	89	87	88	90	90	90
91	90	90	89	87	88	88	90	90	90	90	90	89	89	90	90	90	89	89	90	90	90	90	90	88	88	87	89	90	90	91
91	91	91	89	87	87	87	89	89	90	90	90	89	90	91	91	91	90	89	90	90	90	89	89	87	87	87	89	91	91	91
91	91	90	89	87	86	87	88	88	89	90	90	90	90	91	93	91	90	90	90	90	89	88	88	87	86	87	89	90	91	91
91	91	91	88	86	86	86	87	88	89	90	90	90	90	92	●	92	90	90	90	90	89	88	87	86	86	86	88	91	91	91
91	91	90	89	87	86	87	88	88	89	90	90	90	90	91	93	91	90	90	90	90	89	88	88	87	86	87	89	90	91	91
91	91	91	89	87	87	87	89	89	90	90	90	89	90	91	91	91	90	89	90	90	90	89	89	87	87	87	89	91	91	91
91	90	90	89	87	88	88	90	90	90	90	90	89	89	90	90	90	89	89	90	90	90	90	90	88	88	87	89	90	90	91
90	90	90	88	87	89	90	90	90	90	90	90	89	90	90	90	90	90	89	90	90	90	90	90	90	89	87	88	90	90	90
90	90	90	88	88	90	90	91	91	90	90	90	90	90	90	89	90	90	90	90	90	90	91	91	90	90	88	88	90	90	90
90	90	90	89	89	90	90	91	91	91	90	90	90	90	90	89	90	90	90	90	90	91	91	91	90	90	89	89	90	90	90
90	90	90	90	90	90	91	91	91	91	90	90	90	90	90	89	90	90	90	90	90	91	91	91	91	90	90	90	90	90	90
89	90	90	90	90	90	91	91	91	91	90	90	90	90	90	90	90	90	90	90	90	91	91	91	91	90	90	90	90	90	89
89	90	90	90	90	90	91	91	91	90	90	89	89	90	90	90	90	90	89	89	90	90	91	91	91	90	90	90	90	90	89
89	90	90	90	90	90	90	91	91	90	90	88	88	90	90	90	90	90	88	88	90	90	91	91	90	90	90	90	90	90	89
90	90	90	89	90	90	90	90	90	89	89	87	88	90	90	90	90	90	88	87	89	89	90	90	90	90	90	89	90	90	90
90	90	89	89	90	90	90	90	90	88	88	87	89	90	90	91	90	90	89	87	88	88	90	90	90	90	90	89	89	90	90
92	91	90	89	90	90	90	89	89	87	87	87	89	91	91	91	91	91	89	87	87	87	89	89	90	90	90	89	90	91	92
93	92	90	90	90	90	89	88	88	87	86	87	89	90	91	91	91	90	89	87	86	87	88	88	89	90	90	90	90	92	93
●	92	90	90	90	90	89	88	87	87	86	86	88	91	91	91	91	91	88	86	86	87	87	88	89	90	90	90	90	92	●
93	91	90	90	90	90	89	88	88	87	86	87	89	90	91	91	91	90	89	87	86	87	88	88	89	90	90	90	90	91	93
92	91	90	89	90	90	90	89	89	88	87	87	89	91	91	91	91	91	89	87	87	88	89	89	90	90	90	89	90	91	92
90	90	89	89	90	90	90	90	90	88	88	87	89	90	90	91	90	90	89	87	88	88	90	90	90	90	90	89	89	90	90
90	90	90	89	90	90	90	90	90	90	89	87	88	90	90	90	90	90	88	87	89	90	90	90	90	90	90	89	90	90	90
89	90	90	90	90	90	90	91	91	90	90	88	88	90	90	90	90	90	88	88	90	90	91	91	90	90	90	90	90	90	89
89	90	90	90	90	90	91	91	91	90	90	89	89	90	90	91	90	90	89	89	90	90	91	91	91	90	90	90	90	90	89
89	90	90	90	90	90	91	91	91	91	90	90	90	90	90	90	90	90	90	90	90	91	91	91	91	90	90	90	90	90	89
90	90	90	90	90	90	91	91	91	91	90	90	90	90	90	89	90	90	90	90	90	91	91	91	91	90	90	90	90	90	90
91	90	90	89	89	90	90	91	91	91	90	90	90	90	90	89	90	90	90	90	90	91	91	91	90	90	89	89	90	90	91
90	90	90	88	88	90	90	91	91	90	90	90	90	90	90	89	90	90	90	90	90	90	91	91	90	90	88	88	90	90	90
90	90	90	88	87	89	90	90	90	90	90	90	89	90	90	90	90	90	89	90	90	90	90	90	90	89	87	88	90	90	90
91	90	90	89	87	88	88	90	90	90	90	90	89	89	90	90	90	89	89	90	90	90	90	90	88	88	87	89	90	90	91
91	91	91	89	87	87	88	89	89	90	90	90	89	90	91	92	91	90	89	90	90	90	89	89	88	87	87	89	91	91	91
91	91	90	89	87	86	87	88	88	89	90	90	90	90	92	93	92	90	90	90	90	89	88	88	87	86	87	89	90	91	91
91	91	91	88	86	86	87	87	88	89	90	90	90	90	92	●	92	90	90	90	90	89	88	87	87	86	86	88	91	91	91

probability 3 or more phones are hearing, average pinger, 9.0NM spacing

Figure 14. Hydrophone layout of an average pinger (three or more phones) with spacing set at 9 nautical miles.

53	52	50	38	27	24	28	32	40	49	56	59	64	65	72	●	72	65	64	59	56	49	40	32	28	24	27	38	50	52	53
55	53	50	40	29	26	29	36	41	50	57	60	63	65	70	74	70	65	63	60	57	50	41	36	29	26	29	40	50	53	55
56	53	51	41	30	29	33	41	47	53	56	58	60	63	68	70	68	63	60	58	56	53	47	41	33	29	30	41	51	53	56
56	54	52	42	32	35	38	46	52	55	56	58	58	62	65	66	65	62	58	58	56	55	52	46	38	35	32	42	52	54	56
55	55	53	41	36	41	45	50	52	55	56	59	58	63	65	63	65	63	58	59	56	55	52	50	45	41	36	41	53	55	55
55	55	53	44	41	47	50	51	53	54	55	58	58	62	63	60	63	62	58	58	55	54	53	51	50	47	41	44	53	55	55
58	56	55	49	47	52	51	52	55	56	55	56	58	59	61	58	61	59	58	56	55	56	55	52	51	52	47	49	55	56	58
59	57	57	54	53	54	53	53	55	55	55	55	57	57	58	58	58	57	57	55	55	55	55	53	53	54	53	54	57	57	59
58	58	57	57	55	55	55	55	53	53	54	53	54	57	57	59	57	57	54	53	54	53	53	55	55	55	55	57	57	58	58
58	61	59	58	56	55	56	55	52	51	52	47	49	55	56	58	56	55	49	47	52	51	52	55	56	55	56	58	59	61	58
60	63	62	58	58	55	54	53	51	50	47	41	44	53	55	55	55	53	44	41	47	50	51	53	54	55	58	58	62	63	60
63	65	63	58	59	56	55	52	50	45	41	36	41	53	55	55	55	53	41	36	41	45	50	52	55	56	59	58	63	65	63
66	65	62	58	58	56	55	52	46	38	35	32	42	52	54	56	54	52	42	32	35	38	46	52	55	56	58	58	62	65	66
70	68	63	60	58	56	53	47	41	33	29	30	41	51	53	57	53	51	41	30	29	33	41	47	53	56	58	60	63	68	70
74	70	64	63	60	57	50	41	36	29	26	29	40	50	53	55	53	50	40	29	26	29	36	41	50	57	60	63	64	70	74
●	71	65	64	59	56	49	40	31	27	24	27	38	50	52	53	52	50	38	27	24	27	31	40	49	56	59	64	65	71	●
74	70	65	63	60	57	50	41	36	29	26	29	40	50	53	55	53	50	40	29	26	29	36	41	50	57	60	63	65	70	74
70	68	63	60	58	56	53	47	41	33	29	30	41	51	53	56	53	51	41	30	29	33	41	47	53	56	58	60	63	68	70
66	65	62	58	58	56	55	52	46	37	35	31	41	52	54	56	54	52	41	31	35	37	46	52	55	56	58	58	62	65	66
63	65	63	58	59	56	55	52	50	44	41	36	41	53	55	55	55	53	41	36	41	44	50	52	55	56	59	58	63	65	63
60	63	62	58	58	55	54	53	51	50	47	41	44	53	55	55	55	53	44	41	47	50	51	53	54	55	58	58	62	63	60
58	61	59	58	56	55	56	55	52	51	52	47	49	55	56	58	56	55	49	47	52	51	52	55	56	55	56	58	59	61	58
58	58	57	57	55	55	55	55	53	53	53	53	54	57	57	59	57	57	54	53	53	53	53	55	55	55	55	57	57	58	58
59	57	57	54	53	54	53	53	55	55	55	55	57	57	58	58	58	57	57	55	55	55	55	53	53	54	53	54	57	57	59
58	56	55	49	47	52	51	52	55	56	55	56	58	59	61	58	61	59	58	56	55	56	55	52	51	52	47	49	55	56	58
55	55	53	44	41	47	50	51	53	54	55	58	58	62	63	60	63	62	58	58	55	54	53	51	50	47	41	44	53	55	55
55	55	53	41	36	41	45	50	52	55	56	59	58	63	64	63	64	63	58	59	56	55	52	50	45	41	36	41	53	55	55
56	54	52	42	32	35	38	46	52	55	56	58	58	62	65	66	65	62	58	58	56	55	52	46	38	35	32	42	52	54	56
56	53	51	41	30	29	33	41	47	53	56	58	60	63	68	70	68	63	60	58	56	53	47	41	33	29	30	41	51	53	56
55	53	50	40	29	26	29	36	41	50	57	60	63	64	70	74	70	64	63	60	57	50	41	36	29	26	29	40	50	53	55
53	52	50	38	27	24	28	32	40	49	56	59	64	65	71	●	71	65	64	59	56	49	40	32	28	24	27	38	50	52	53
55	53	50	40	29	26	29	36	41	50	57	60	63	64	70	74	70	64	63	60	57	50	41	36	29	26	29	40	50	53	55
56	53	51	41	30	29	33	41	47	53	56	58	60	63	68	70	68	63	60	58	56	53	47	41	33	29	30	41	51	53	56
56	54	52	42	32	35	38	46	52	55	56	58	58	62	65	66	65	62	58	58	56	55	52	46	38	35	32	42	52	54	56
55	55	53	41	36	41	45	50	52	55	56	59	58	63	64	63	64	63	58	59	56	55	52	50	45	41	36	41	53	55	55
55	55	53	44	41	47	50	51	53	54	55	58	58	62	63	60	63	62	58	58	55	54	53	51	50	47	41	44	53	55	55
58	56	55	49	47	52	51	52	55	56	55	56	58	59	61	58	61	59	58	56	55	56	55	52	51	52	47	49	55	56	58
59	57	57	54	53	54	53	53	55	55	55	55	57	57	58	58	58	57	57	55	55	55	55	53	53	54	53	54	57	57	59
58	58	57	57	55	55	55	55	53	53	53	53	54	57	57	59	57	57	54	53	53	53	53	55	55	55	55	57	57	58	58
58	61	59	58	56	55	56	55	52	51	52	47	49	55	56	58	56	55	49	47	52	51	52	55	56	55	56	58	59	61	58
60	63	62	58	58	55	54	53	51	50	47	41	44	53	55	55	55	53	44	41	47	50	51	53	54	55	58	58	62	63	60
63	65	63	58	59	56	55	52	50	44	41	36	41	53	55	55	55	53	41	36	41	44	50	52	55	56	59	58	63	65	63
66	65	62	58	58	56	55	52	46	37	35	31	41	52	54	56	54	52	41	31	35	37	46	52	55	56	58	58	62	65	66
70	68	63	60	58	56	53	47	41	33	29	30	41	51	53	56	53	51	41	30	29	33	41	47	53	56	58	60	63	68	70
74	70	65	63	60	57	50	41	36	29	26	29	40	50	53	55	53	50	40	29	26	29	36	41	50	57	60	63	65	70	74
●	71	65	64	59	56	49	40	31	27	24	26	38	50	52	53	52	50	38	26	24	27	31	40	49	56	59	64	65	71	●
74	70	64	63	60	57	50	41	36	29	26	29	40	50	53	55	53	50	40	29	26	29	36	41	50	57	60	63	64	70	74
70	68	63	60	58	56	53	47	41	33	29	30	41	51	53	57	53	51	41	30	29	33	41	47	53	56	58	60	63	68	70
66	65	62	58	58	56	55	52	46	38	35	32	42	52	54	56	54	52	42	32	35	38	46	52	55	56	58	58	62	65	66
63	65	63	58	59	56	55	52	50	45	41	36	41	53	55	55	55	53	41	36	41	45	50	52	55	56	59	58	63	65	63
60	63	62	58	58	55	54	53	51	50	47	41	44	53	55	55	55	53	44	41	47	50	51	53	54	55	58	58	62	63	60
58	61	59	58	56	55	56	55	52	51	52	47	49	55	56	58	56	55	49	47	52	51	52	55	56	55	56	58	59	61	58
58	58	57	57	55	55	55	55	53	53	54	53	54	57	57	59	57	57	54	53	54	53	53	55	55	55	55	57	57	58	58
59	57	57	54	53	54	53	53	55	55	55	55	57	57	58	58	58	57	57	55	55	55	55	53	53	54	53	54	57	57	59
58	56	55	49	47	52	51	52	55	56	55	56	58	59	61	58	61	59	58	56	55	56	55	52	51	52	47	49	55	56	58
55	55	53	44	41	47	50	51	53	54	55	58	58	62	63	60	63	62	58	58	55	54	53	51	50	47	41	44	53	55	55
55	55	53	41	36	41	45	50	52	55	56	59	58	63	65	63	65	63	58	59	56	55	52	50	45	41	36	41	53	55	55
56	54	52	42	32	35	38	46	52	55	56	58	58	62	65	66	65	62	58	58	56	55	52	46	38	35	32	42	52	54	56
56	53	51	41	30	29	33	41	47	53	56	58	60	63	68	70	68	63	60	58	56	53	47	41	33	29	30	41	51	53	56
55	53	50	40	29	26	29	36	41	50	57	60	63	65	70	74	70	65	63	60	57	50	41	36	29	26	29	40	50	53	55
53	52	50	38	27	24	28	32	40	49	56	59	64	65	72	●	72	65	64	59	56	49	40	32	28	24	27	38	50	52	53

probability 4 or more phones are hearing, average pinger, 9.0NM spacing

Figure 15. Hydrophone layout of an average pinger (four or more phones) with spacing set at 9 nautical miles.

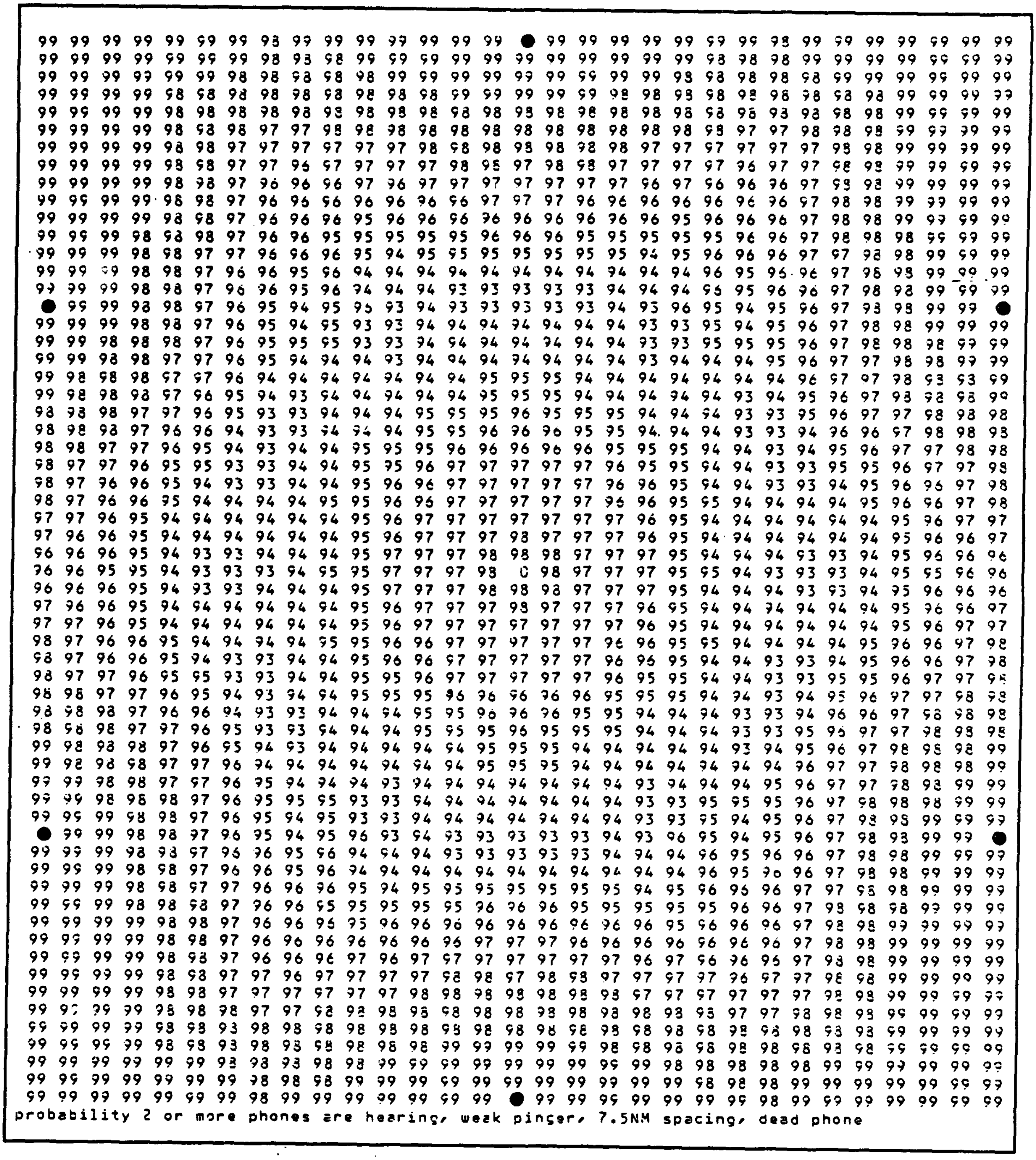

Figure 16. The failure of the center phone (two or more phones) of a weak pinger for a 7.5-nautical-mile layout.

90	89	89	88	86	84	84	84	85	86	88	90	91	92	93	●	93	92	91	90	88	86	85	84	84	84	86	88	89	89	90
90	89	89	88	86	84	83	82	83	84	86	90	91	91	93	93	93	91	91	90	86	84	83	82	83	84	86	88	89	89	90
91	90	88	87	85	83	83	81	82	82	85	88	89	90	92	92	92	90	89	88	85	82	82	81	83	83	85	87	88	90	91
91	90	88	87	84	82	80	80	80	81	84	86	88	89	90	91	90	89	88	86	84	81	80	80	80	82	84	87	88	90	91
91	90	88	87	83	81	79	77	78	80	82	84	86	88	88	89	88	88	86	84	82	80	78	77	79	81	83	87	88	90	91
92	90	88	86	83	81	77	74	75	77	80	83	84	87	87	87	87	87	84	83	80	77	75	74	77	81	83	86	88	90	92
92	91	88	86	83	80	76	71	72	74	78	79	82	85	86	85	86	85	82	79	78	74	72	71	76	80	83	86	88	91	92
92	91	89	86	82	80	75	70	69	71	75	75	79	82	83	83	83	82	79	75	75	71	69	70	75	80	82	86	89	91	92
92	92	90	86	82	80	75	69	66	68	72	72	76	78	80	80	80	78	76	72	72	68	66	69	75	80	82	86	90	92	92
93	92	90	87	84	80	74	68	66	66	69	70	73	74	77	79	77	74	73	70	69	66	66	68	74	80	84	87	90	92	93
93	92	91	88	84	80	74	68	66	65	67	68	70	71	73	75	73	71	70	68	67	65	66	68	74	80	84	88	91	92	93
93	92	91	88	84	80	75	69	67	63	65	65	67	69	71	71	71	69	67	65	65	63	67	69	75	80	84	88	91	92	93
93	92	90	87	84	79	74	69	68	69	62	61	65	66	67	67	67	66	65	61	62	69	68	69	74	79	84	87	90	92	93
94	92	90	88	84	78	72	68	67	70	59	59	63	64	63	63	63	64	63	59	59	70	67	68	72	78	84	88	90	92	94
94	93	90	88	85	78	72	68	65	68	55	58	62	61	59	60	59	61	62	58	55	68	65	68	72	78	85	88	90	93	94
●	93	90	88	85	79	73	67	64	66	68	56	59	58	58	57	58	58	59	56	68	66	64	67	73	79	85	88	90	93	●
93	92	90	87	84	78	71	67	65	67	54	57	62	61	60	60	60	61	62	57	54	67	65	67	71	78	84	87	90	92	93
93	91	89	86	83	77	71	66	66	68	57	59	63	64	63	63	63	64	63	59	57	68	66	66	71	77	83	86	89	91	93
92	90	88	85	81	76	71	66	65	59	60	60	64	65	66	65	66	65	64	60	60	59	65	66	71	76	81	85	88	90	92
90	89	87	84	80	76	71	65	63	60	63	63	65	66	69	69	69	66	65	63	63	60	63	65	71	76	80	84	87	89	90
89	88	87	83	79	75	69	63	61	61	64	65	67	68	70	72	70	68	67	65	64	61	61	63	69	75	79	83	87	88	89
88	87	85	81	76	73	66	61	58	62	65	66	69	70	73	75	73	70	69	66	65	62	58	61	66	73	76	81	85	87	88
86	84	82	78	73	71	65	60	59	63	67	68	72	74	76	77	76	74	72	68	67	63	59	60	65	71	73	78	82	84	86
84	82	79	75	71	69	63	59	60	64	69	70	74	78	79	79	79	78	74	70	69	64	60	59	63	69	71	75	79	82	84
83	79	75	73	68	66	61	58	62	65	71	73	77	81	82	82	82	81	77	73	71	65	62	58	61	66	68	73	75	79	83
80	76	72	70	67	65	61	59	63	67	72	76	79	83	84	84	84	83	79	76	72	67	63	59	61	65	67	70	72	76	80
77	75	71	68	64	63	60	61	64	69	73	77	80	84	84	85	84	84	80	77	73	69	64	61	60	63	64	68	71	75	77
74	72	69	66	61	61	59	63	65	68	73	78	82	84	86	86	86	84	82	78	73	68	65	63	59	61	61	66	69	72	74
71	68	67	65	60	58	60	63	65	68	73	79	83	85	87	87	87	85	83	79	73	68	65	63	60	58	60	65	67	68	71
69	65	65	64	59	55	57	61	65	68	74	81	84	85	87	88	87	85	84	81	74	68	65	61	57	55	59	64	65	65	69
66	64	62	61	57	53	56	61	65	69	74	81	84	86	88	0	88	86	84	81	74	69	65	61	56	53	57	61	62	64	66
69	65	65	64	59	55	57	61	65	68	74	81	84	85	87	88	87	85	84	81	74	68	65	61	57	55	59	64	65	65	69
71	68	67	65	60	58	60	63	65	68	73	79	83	85	87	87	87	85	83	79	73	68	65	63	60	58	60	65	67	68	71
74	72	69	66	61	61	59	63	65	68	73	78	82	84	86	86	86	84	82	78	73	68	65	63	59	61	61	66	69	72	74
77	75	71	68	64	63	60	61	64	69	73	77	80	84	84	85	84	84	80	77	73	69	64	61	60	63	64	68	71	75	77
80	76	72	70	67	65	61	59	63	67	72	76	79	83	84	84	84	83	79	76	72	67	63	59	61	65	67	70	72	76	80
83	79	75	73	68	66	61	58	62	65	71	73	77	81	82	82	82	81	77	73	71	65	62	58	61	66	68	73	75	79	83
84	82	79	75	71	69	63	59	60	64	69	70	74	78	79	79	79	78	74	70	69	64	60	59	63	69	71	75	79	82	84
86	84	82	78	73	71	65	60	59	63	67	68	72	74	76	77	76	74	72	68	67	63	59	60	65	71	73	78	82	84	86
88	87	85	81	76	73	66	61	58	62	65	66	69	70	73	75	73	70	69	66	65	62	58	61	66	73	76	81	85	87	88
89	88	87	83	79	75	69	63	61	61	64	65	67	68	70	72	70	68	67	65	64	61	61	63	69	75	79	83	87	88	89
90	89	87	84	80	76	71	65	63	60	63	63	65	66	69	69	69	66	65	63	63	60	63	65	71	76	80	84	87	89	90
92	90	88	85	81	76	71	66	65	59	60	60	64	65	66	65	66	65	64	60	60	59	65	66	71	76	81	85	88	90	92
93	91	89	86	83	77	71	66	66	68	57	59	63	64	63	63	63	64	63	59	57	68	66	66	71	77	83	86	89	91	93
93	92	90	87	84	78	71	67	65	67	54	57	62	61	60	60	60	61	62	57	54	67	65	67	71	78	84	87	90	92	93
●	93	90	88	85	79	73	67	64	66	68	56	59	58	58	57	58	58	59	56	68	66	64	67	73	79	85	88	90	93	●
94	93	90	88	85	78	72	68	65	68	55	58	62	61	59	60	59	61	62	58	55	68	65	68	72	78	85	88	90	93	94
94	92	90	88	84	78	72	68	67	70	59	59	63	64	63	63	63	64	63	59	59	70	67	68	72	78	84	88	90	92	94
93	92	90	87	84	79	74	69	68	69	62	61	65	66	67	67	67	66	65	61	62	69	68	69	74	79	84	87	90	92	93
93	92	91	88	84	80	75	69	67	63	65	65	67	69	71	71	71	69	67	65	65	63	67	69	75	80	84	88	91	92	93
93	92	91	88	84	80	74	68	66	65	67	68	70	71	73	75	73	71	70	68	67	65	66	68	74	80	84	88	91	92	93
93	92	90	87	84	80	74	68	66	66	69	70	73	74	77	79	77	74	73	70	69	66	66	68	74	80	84	87	90	92	93
92	92	90	86	82	80	75	69	66	68	72	72	76	78	80	80	80	78	76	72	72	68	66	69	75	80	82	86	90	92	92
92	91	89	86	82	80	75	70	69	71	75	75	79	82	83	83	83	82	79	75	75	71	69	70	75	80	82	86	89	91	92
92	91	88	86	83	80	76	71	72	74	78	79	82	85	86	85	86	85	82	79	78	74	72	71	76	80	83	86	88	91	92
92	90	88	86	83	81	77	74	75	77	80	83	84	87	87	87	87	87	84	83	80	77	75	74	77	81	83	86	88	90	92
91	90	88	87	83	81	79	77	78	80	82	84	86	88	88	89	88	88	86	84	82	80	78	77	79	81	83	87	88	90	91
91	90	88	87	84	82	80	80	80	81	84	86	88	89	90	91	90	89	88	86	84	81	80	80	80	82	84	87	88	90	91
91	90	88	87	85	83	83	81	82	82	85	88	89	90	92	92	92	90	89	88	85	82	82	81	83	83	85	87	88	90	91
90	89	89	88	86	84	83	82	83	84	86	90	91	91	93	93	93	91	91	90	86	84	83	82	83	84	86	88	89	89	90
90	89	89	88	86	84	84	84	85	86	88	90	91	92	93	●	93	92	91	90	88	86	85	84	84	84	86	88	89	89	90

probability 3 or more phones are hearing, weak pinger, 7.5NM spacing, dead phone

Figure 17. The failure of the center phone (three or more phones) of a weak pinger for a 7.5-nautical-mile layout.

52	51	48	45	36	28	31	33	37	42	50	61	66	70	74	●	74	70	66	61	50	42	37	33	31	28	36	45	48	51	52
54	51	48	44	35	28	28	29	32	37	47	59	65	68	72	73	72	68	65	59	47	37	32	29	28	28	35	44	48	51	54
55	52	47	43	34	28	25	26	28	33	43	54	61	65	69	71	69	65	61	54	43	33	28	26	25	28	34	43	47	52	55
57	53	47	42	33	27	18	23	25	31	40	49	57	63	65	67	65	63	57	49	40	31	25	23	18	27	33	42	47	53	57
59	54	48	42	33	26	17	16	20	28	38	46	53	60	61	63	61	60	53	46	38	28	20	16	17	26	33	42	48	54	59
61	55	49	41	32	26	16	8	14	23	34	43	50	58	59	59	59	58	50	43	34	23	14	8	16	26	32	41	49	55	61
64	58	50	42	31	25	14	5	9	18	30	36	44	52	55	54	55	52	44	36	30	18	9	5	14	25	31	42	50	58	64
65	61	53	44	33	26	14	4	6	15	25	30	38	45	48	48	48	45	38	30	25	15	6	4	14	26	33	44	53	61	65
67	64	57	47	35	28	15	6	4	13	22	26	33	37	41	42	41	37	33	26	22	13	4	6	15	28	35	47	57	64	67
69	67	61	51	40	31	17	8	8	12	19	23	28	30	34	38	34	30	28	23	19	12	8	8	17	31	40	51	61	67	69
71	68	64	54	45	34	21	12	11	12	19	21	24	25	28	31	28	25	24	21	19	12	11	12	21	34	45	54	64	68	71
72	68	64	56	46	36	25	17	16	12	18	19	21	22	24	24	24	22	21	19	18	12	16	17	25	36	46	56	64	68	72
74	69	65	57	47	36	26	19	21	24	16	17	19	18	18	15	18	18	19	17	16	24	21	19	26	36	47	57	65	69	74
75	71	65	59	50	37	26	20	22	27	15	16	17	16	11	10	11	16	17	16	15	27	22	20	26	37	50	59	65	71	75
75	72	66	60	52	38	27	21	22	26	13	14	16	11	6	5	6	11	16	14	13	26	22	21	27	38	52	60	66	72	75
●	72	65	60	52	38	28	22	21	25	27	13	12	7	4	1	4	7	12	13	27	25	21	22	28	38	52	60	65	72	●
74	71	64	59	51	37	26	21	21	25	13	14	16	11	6	5	6	11	16	14	13	25	21	21	26	37	51	59	64	71	74
72	68	63	57	48	36	25	20	21	26	14	15	17	15	11	9	11	15	17	15	14	26	21	20	25	36	48	57	63	68	72
69	65	61	54	44	34	24	18	20	12	16	17	18	18	17	15	17	18	18	17	16	12	20	18	24	34	44	54	61	65	69
65	62	59	51	42	33	23	16	15	12	17	19	20	20	22	22	22	20	20	19	17	12	15	16	23	33	42	51	59	62	65
62	60	57	48	40	31	20	11	10	11	18	20	22	23	26	29	26	23	22	20	18	11	10	11	20	31	40	48	57	60	62
57	56	52	43	34	27	15	7	4	11	18	21	26	28	32	35	32	28	26	21	18	11	4	7	15	27	34	43	52	56	57
51	50	46	37	28	23	13	5	3	11	20	23	30	34	38	39	38	34	30	23	20	11	3	5	13	23	28	37	46	50	51
46	43	38	33	25	21	11	3	5	13	22	26	34	41	45	44	45	41	34	26	22	13	5	3	11	21	25	33	38	43	46
42	36	31	28	22	18	11	4	7	15	26	32	40	48	51	50	51	48	40	32	26	15	7	4	11	18	22	28	31	36	42
34	30	26	24	21	18	11	7	11	19	29	37	45	53	54	54	54	53	45	37	29	19	11	7	11	18	21	24	26	30	34
26	25	23	21	19	17	12	12	15	22	31	39	47	54	56	57	56	54	47	39	31	22	15	12	12	17	19	21	23	25	26
18	19	19	19	17	16	12	16	18	23	32	41	50	56	59	61	59	56	50	41	32	23	18	16	12	16	17	19	19	19	18
11	12	17	18	16	14	15	17	19	23	33	45	53	57	61	63	61	57	53	45	33	23	19	17	15	14	16	18	17	12	11
6	7	12	16	15	13	14	17	20	24	34	47	54	58	63	64	63	58	54	47	34	24	20	17	14	13	15	16	12	7	6
1	4	8	12	13	12	14	17	21	26	35	48	55	59	63	[illegible]	63	59	55	48	35	26	21	17	14	12	13	12	8	4	1
6	7	12	16	15	13	14	17	20	24	34	47	54	58	63	64	63	58	54	47	34	24	20	17	14	13	15	16	12	7	6
11	12	17	18	16	14	15	17	19	23	33	45	53	57	61	63	61	57	53	45	33	23	19	17	15	14	16	18	17	12	11
18	19	19	19	17	16	12	16	18	23	32	41	50	56	59	61	59	56	50	41	32	23	18	16	12	16	17	19	19	19	18
26	25	23	21	19	17	12	12	15	22	31	39	47	54	56	57	56	54	47	39	31	22	15	12	12	17	19	21	23	25	26
34	30	26	24	21	18	11	7	11	19	29	37	45	53	54	54	54	53	45	37	29	19	11	7	11	18	21	24	26	30	34
42	36	31	28	22	18	11	4	7	15	26	32	40	48	51	50	51	48	40	32	26	15	7	4	11	18	22	28	31	36	42
46	43	38	33	25	21	11	3	5	13	22	26	34	41	45	44	45	41	34	26	22	13	5	3	11	21	25	33	38	43	46
51	50	46	37	28	23	13	5	3	11	20	23	30	34	38	39	38	34	30	23	20	11	3	5	13	23	28	37	46	50	51
57	56	52	43	34	27	15	7	4	11	18	21	26	28	32	35	32	28	26	21	18	11	4	7	15	27	34	43	52	56	57
62	60	57	48	40	31	20	11	10	11	18	20	22	23	26	29	26	23	22	20	18	11	10	11	20	31	40	48	57	60	62
65	62	59	51	42	33	23	16	15	12	17	19	20	20	22	22	22	20	20	19	17	12	15	16	23	33	42	51	59	62	65
69	65	61	54	44	34	24	18	20	12	16	17	18	18	17	15	17	18	18	17	16	12	20	18	24	34	44	54	61	65	69
72	68	63	57	48	36	25	20	21	26	14	15	17	15	11	9	11	15	17	15	14	26	21	20	25	36	48	57	63	68	72
74	71	64	59	51	37	26	21	21	25	13	14	16	11	6	5	6	11	16	14	13	25	21	21	26	37	51	59	64	71	74
●	72	65	60	52	38	28	22	21	25	27	13	11	7	4	1	4	7	11	13	27	25	21	22	28	38	52	60	65	72	●
75	72	66	60	52	38	27	21	22	26	13	14	16	11	6	5	6	11	16	14	13	26	22	21	27	38	52	60	66	72	75
75	71	65	59	50	37	26	20	22	27	15	16	17	16	11	10	11	16	17	16	15	27	22	20	26	37	50	59	65	71	75
74	69	65	57	47	36	26	19	21	24	16	17	19	18	18	15	18	18	19	17	16	24	21	19	26	36	47	57	65	69	74
72	68	64	56	46	36	25	17	16	12	18	19	21	22	24	24	24	22	21	19	18	12	16	17	25	36	46	56	64	68	72
71	68	64	54	45	34	21	12	11	12	19	21	24	25	28	31	28	25	24	21	19	12	11	12	21	34	45	54	64	68	71
69	67	61	51	40	31	17	8	8	12	19	23	28	30	34	38	34	30	28	23	19	12	8	8	17	31	40	51	61	67	69
67	64	57	47	35	28	15	6	4	13	22	26	33	37	41	42	41	37	33	26	22	13	4	6	15	28	35	47	57	64	67
65	61	53	44	33	26	14	4	6	15	25	30	38	45	48	48	48	45	38	30	25	15	6	4	14	26	33	44	53	61	65
64	58	50	42	31	25	14	5	9	18	30	36	44	52	55	54	55	52	44	36	30	18	9	5	14	25	31	42	50	58	64
61	55	49	41	32	26	16	8	14	23	34	43	50	58	59	59	59	58	50	43	34	23	14	8	16	26	32	41	49	55	61
59	54	48	42	33	26	17	16	20	28	38	46	53	60	61	63	61	60	53	46	38	28	20	16	17	26	33	42	48	54	59
57	53	47	42	33	27	18	23	25	31	40	49	57	63	65	67	65	63	57	49	40	31	25	23	18	27	33	42	47	53	57
55	52	47	43	34	28	25	26	28	33	43	54	61	65	69	71	69	65	61	54	43	33	28	26	25	28	34	43	47	52	55
54	51	48	44	35	28	28	29	32	37	47	59	65	68	72	73	72	68	65	59	47	37	32	29	28	28	35	44	48	51	54
52	51	48	45	36	28	31	33	37	42	50	61	66	70	74	●	74	70	66	61	50	42	37	33	31	28	36	45	48	51	52

probability 4 or more phones are hearing, weak pinger, 7.5NM spacing, dead phone

Figure 18. The failure of the center phone (four or more) of a weak pinger for a 7.5-nautical-mile layout.

tracker continually switches phones in and out to ensure that the seven closest phones are assigned. The underwater-tracking software has recently been modified to allow an operator to define a special fixed array of seven hydrophones that will remain assigned no matter where the target is on the range. By choosing seven phones that resemble a sparsely configured large-area range, the actual tracking characteristics can be experimented with and confirmed.

The BSURE consists of two parallel hydrophone strings separated by about 7 nautical miles. Each string has 9 hydrophones spaced at 4 nautical mile intervals. By selecting every other phone on each string, a large-area range with 8 nautical mile spacing can be simulated. Figures 19 through 21 show the expected performance of an average pinger on northern BSURE using a fixed seven phone array consisting of phones A-9, A-7, A-5, A-3, B-8, B-6, and B-4. Notice that the tracking characteristics should be acceptable as long as the target stays in between the strings.

From time to time during normal range operations, this special array was called up to track targets. The solution files were later examined for any tracking irregularities. Three- and four-phone solutions were consistently available for almost every ping period. Two-phone solutions were rarely observed unless the target wandered outside the strings. The only tracking difficulty noticed is a problem often encountered even when all 18 BSURE phones are available. If the target is near or directly on top of a string, and the pinger is so weak that the other string cannot detect it, the software has no means of knowing whether the target is to the left or the right of the string. During acquisition this problem is especially troublesome, because there is no prior knowledge to rely upon. If the target is already being tracked and begins crossing the string, the tracking accuracy of the two-dimension spherical algorithm degrades significantly causing the track to bounce around. With widely spaced hydrophones, a large-area range will undoubtedly encounter this problem more often for especially weak pingers.

0	0	0	0	0	0	0	0	0	0	0	0	6	8	13	17	21	13	6	2	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	3	6	15	24	35	39	31	12	4	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	6	14	24	43	52	50	43	21	6	2	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	3	9	18	42	58	61	60	53	33	12	5	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	6	15	33	53	66	70	63	61	46	15	5	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	6	20	51	66	73	76	75	68	55	21	6	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	8	18	35	53	74	80	81	80	73	60	30	9	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	6	13	23	50	70	79	84	86	83	77	64	37	12	3	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	6	6	19	32	65	77	84	88	88	86	80	68	44	14	5	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	4	6	15	26	47	76	85	89	90	91	88	83	71	49	15	6	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	6	13	23	46	69	86	91	94	94	93	91	85	75	55	18	6	0	0	0	0	0	0	0	0	0
0	0	0	0	0	4	9	18	43	64	79	90	●	96	97	96	92	88	77	57	22	11	0	0	0	0	0	0	0	0	0
0	0	0	0	0	5	14	34	60	71	86	93	96	97	97	97	95	90	80	62	27	12	4	0	0	0	0	0	0	0	0
0	0	0	0	2	8	20	51	67	78	90	95	97	98	98	98	97	93	85	68	32	19	6	2	0	0	0	0	0	0	0
0	0	0	0	2	11	33	59	73	82	93	96	98	99	99	99	98	96	90	76	45	24	12	6	0	0	0	0	0	0	0
0	0	0	0	2	13	45	64	77	86	94	97	99	99	99	99	99	●	93	82	64	40	17	8	3	0	0	0	0	0	0
0	0	0	0	3	20	50	68	80	85	95	97	99	99	100	100	99	98	95	85	71	58	30	13	5	0	0	0	0	0	0
0	0	0	0	3	26	52	69	82	89	96	98	99	100	100	100	99	99	97	88	77	64	47	18	7	1	0	0	0	0	0
0	0	0	0	3	23	33	70	82	89	95	98	99	100	100	100	100	99	98	90	81	70	58	30	11	2	0	0	0	0	0
0	0	0	0	3	24	52	69	81	89	95	98	99	100	100	100	100	99	98	92	85	75	63	43	13	2	0	0	0	0	0
0	0	0	0	3	18	50	67	79	89	94	98	99	100	100	100	100	99	98	94	88	79	67	49	18	2	0	0	0	0	0
0	0	0	0	2	13	42	64	76	86	94	98	99	100	100	100	100	99	98	95	88	81	69	51	24	3	0	0	0	0	0
0	0	0	0	3	[illegible]	31	60	74	84	93	98	99	100	100	100	100	99	98	95	88	82	69	52	26	3	0	0	0	0	0
0	0	0	0	1	6	22	52	71	85	94	99	99	100	100	100	100	99	98	96	89	81	69	51	24	3	0	0	0	0	0
0	0	0	0	0	8	20	41	72	87	95	98	●	100	100	100	99	99	98	95	88	80	67	49	17	2	0	0	0	0	0
0	0	0	0	0	8	20	42	73	87	95	98	99	100	100	100	100	99	98	95	87	78	64	41	13	2	0	0	0	0	0
0	0	0	0	1	7	22	53	72	85	95	98	99	100	100	100	100	99	98	94	85	75	60	31	10	2	0	0	0	0	0
0	0	0	0	3	11	32	60	76	85	95	98	99	100	100	100	100	99	98	95	85	72	52	22	6	1	0	0	0	0	0
0	0	0	0	2	13	43	65	78	87	95	98	99	100	100	100	100	99	98	95	87	73	41	20	8	0	0	0	0	0	0
0	0	0	0	3	19	50	67	80	88	95	98	99	100	100	100	100	●	98	95	87	73	42	20	8	0	0	0	0	0	0
0	0	0	0	3	25	52	69	81	89	96	98	99	100	100	100	100	99	99	94	85	71	53	22	6	1	0	0	0	0	0
0	0	0	0	3	28	53	70	82	89	96	98	99	100	100	100	100	99	98	93	84	74	60	31	11	3	0	0	0	0	0
0	0	0	0	3	25	52	69	81	89	95	98	99	100	100	100	100	99	98	94	87	77	65	43	13	2	0	0	0	0	0
0	0	0	0	3	19	50	67	80	89	94	98	99	100	100	100	100	99	98	94	89	80	67	50	18	3	0	0	0	0	0
0	0	0	0	2	13	43	65	77	87	94	99	99	100	100	100	100	99	98	95	89	81	69	52	25	3	0	0	0	0	0
0	0	0	0	3	11	32	61	74	85	93	99	99	100	100	100	100	99	98	95	89	83	70	54	28	3	0	0	0	0	0
0	0	0	0	1	7	23	54	71	85	94	99	100	100	100	100	100	99	98	96	89	82	70	53	27	3	0	0	0	0	0
0	0	0	0	0	7	20	42	73	87	95	99	99	100	100	100	100	99	98	95	88	80	68	51	20	3	0	0	0	0	0
0	0	0	0	0	8	20	41	73	88	95	98	●	100	100	100	99	99	98	95	86	77	64	46	13	2	0	0	0	0	0
0	0	0	0	1	6	22	52	72	85	95	98	99	100	100	100	100	99	97	93	82	74	59	34	11	3	0	0	0	0	0
0	0	0	0	3	10	30	60	75	85	95	98	99	100	100	100	99	99	96	91	78	68	52	21	8	2	0	0	0	0	0
0	0	0	0	2	13	41	64	78	87	95	96	99	99	100	100	99	98	95	88	73	61	34	15	5	0	0	0	0	0	0
0	0	0	0	3	17	50	67	80	89	95	98	99	99	100	100	99	●	95	83	67	44	18	9	4	0	0	0	0	0	0
0	0	0	0	3	24	52	69	81	89	96	98	99	99	99	99	99	98	94	76	50	24	14	6	0	0	0	0	0	0	0
0	0	0	0	3	28	53	70	83	89	96	98	99	99	99	99	99	97	91	64	32	15	6	4	0	0	0	0	0	0	0
0	0	0	0	3	27	53	70	82	89	95	97	99	99	99	99	98	95	88	57	29	9	6	0	0	0	0	0	0	0	0
0	0	0	0	3	21	51	68	80	88	94	97	98	99	99	99	98	95	85	57	25	10	0	0	0	0	0	0	0	0	0
0	0	0	0	2	14	47	65	77	86	92	96	98	99	99	98	97	94	82	59	23	6	0	0	0	0	0	0	0	0	0
0	0	0	0	2	12	35	60	72	81	89	95	97	98	98	98	96	92	78	58	17	6	0	0	0	0	0	0	0	0	0
0	0	0	0	2	8	22	53	66	76	84	93	95	97	97	97	95	89	77	60	17	6	0	0	0	0	0	0	0	0	0
0	0	0	0	0	5	15	36	59	70	79	88	93	95	96	95	93	86	75	58	17	6	0	0	0	0	0	0	0	0	0
0	0	0	0	0	5	10	19	43	62	71	80	●	92	93	93	89	84	73	55	17	6	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	6	14	24	43	60	69	83	88	88	87	85	80	70	53	16	5	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	4	7	15	21	38	50	65	76	79	81	80	76	65	49	14	5	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	6	7	14	22	29	39	61	70	73	74	69	60	42	12	4	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	6	7	10	18	27	40	58	65	65	61	52	33	10	3	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	5	7	12	15	23	38	50	56	52	44	25	6	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	2	9	13	18	28	36	36	29	12	3	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	3	6	11	16	17	17	13	4	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	4	6	8	10	10	7	2	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	6	5	4	3	1	0	0	0	0	0	0	0	0	0	0	0

probability 2 or more phones are hearing, average pinger

Figure 19. Every other phone (two or more phones) on north BSURE.

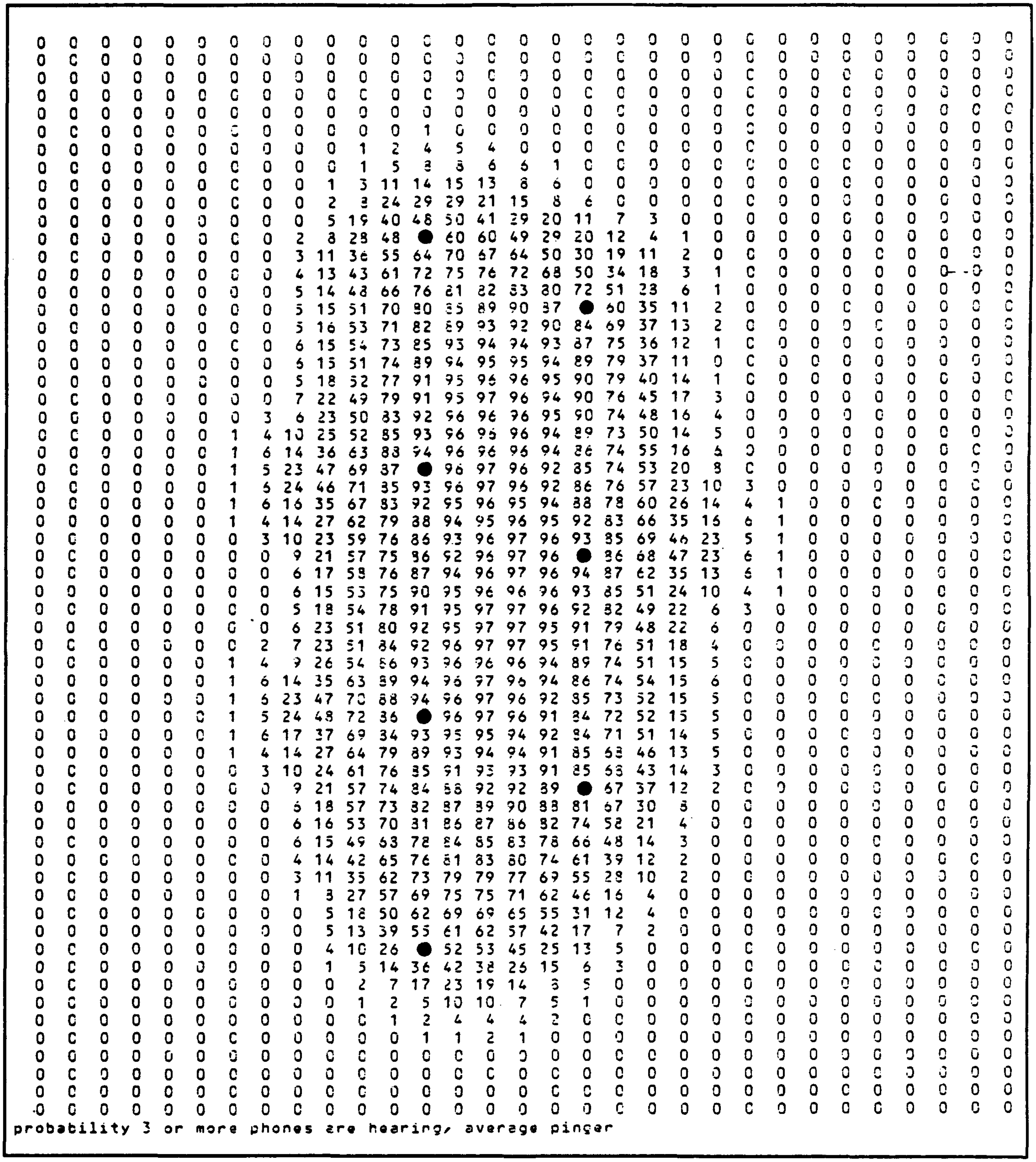

Figure 20. Every other phone (three or more phones) on north BSURE.

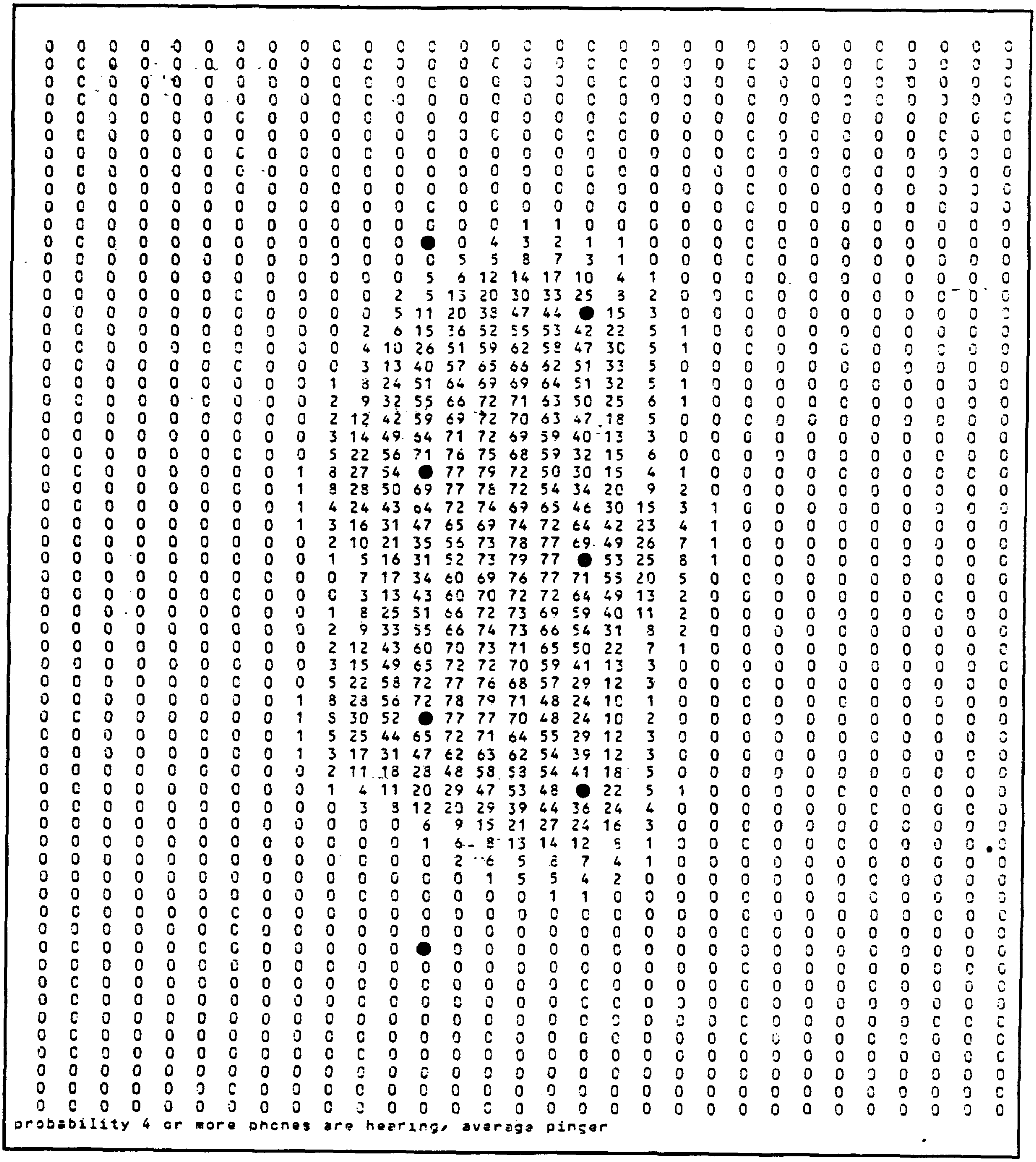

Figure 21. Every other phone (four or more phones) on North BSURE.

SUMMARY

A new approach was discussed to designing a large-area underwater-tracking range using hearing-range statistics gathered from a large number of range pingers being used in everyday operations. These statistics were used to extend hydrophone base lines to the maximum to reduce installation costs. Predictions of the tracking performance of the new range were then made by calculating the probability that "n" phones or more would hear the pinger at different locations. Finally, the tracking predictions were verified by using a sparsely configured array of hydrophones on BSURE to track underwater targets during normal operations.

The only design criteria considered was whether the range should be able to track a weak pinger or an extremely weak pinger (for example, 1 or 2 standard deviations below the mean). By choosing a 7.5 nautical mile spacing between hydrophones, it was shown that a weak pinger (defined as 1 standard deviation down) could be tracked without any problems. Even a dead hydrophone could be accommodated without too much loss in capability. In the conservatively designed ranges of today, there is occasionally a pinger that is too weak to track, and backup procedures are initiated. Submarines carry a backup pinger, MK-30s carry an F beacon and an end-of-run acoustic locator to aid in recovery, and torpedoes have an acoustic locator. By increasing the spacing between phones, the range will experience more "failed" pingers and will have to resort to these backup procedures more often. At the same time though, the Navy will be able to build much larger ranges for the available dollars.