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U. S. NAVAL AIR DEVELOPMENT CENTER
JOHNSVILLE, PENNSYLVANIA

Aeronautical Electronic and Electrical Laboratory

REPORT NO. NADC-EL-N6301 - TECHNICAL NOTE, A GAMMA GUIDANCE SYSTEM FOR HELICOPTER FLIGHT-FORMATION CONTROL

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Preliminary studies confirm the feasibility of using gamma radiation as the sensing signal for an all-weather, short-range, stationkeeping, formation-control system for helicopters. This report discusses three methods investigated for determining range, azimuth, and elevation. The eclipse method, which uses the difference signal between an unshielded and a shielded detector, was found to be capable of providing an accuracy of ±10 percent in range and ±1 degree in azimuth and elevation. It is recommended that expanded effort be directed toward the development of such a gamma guidance system.

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Technical Director

SUMMARY

INTRODUCTION

A formation-control system for helicopters performing close-order maneuvers encounters severe obstacles in all-weather day and night operations. Stationkeeping under these conditions presents a difficult challenge for the optical, infrared, and radar devices now in use for such control. Darkness, clouds, and ground fog make visual and television methods undependable; the varying density of clouds and moisture, and spurious heat signals from the sun and other sources degrade infrared; and the short ranges (60 to 1000 feet) complicate the radar problem. No such difficulties influence the propagation and use of gamma radiation, suggesting that its application to the stationkeeping problem is worth investigating.

SUMMARY OF RESULTS

Theoretical analyses and preliminary laboratory experiments indicate that the use of gamma radiation as the sensing signal for a formation-control system is feasible and promising. Reports on flight tests of related nuclear devices, such as proximity scorers and miss-distance indicators, verify the efficacy of gamma ranging devices in aircraft. Accordingly, a gamma range was instrumented in the Center's nuclear facility, and various methods for determining range, azimuth, and elevation have been investigated. Three arrangements of sources, detectors, and visual presentations were found to be particularly promising, for which data have been accumulated and an analysis made of relative merits. One arrangement, the eclipse method, utilizes the difference signal between an unshielded and a shielded detector, and can provide an accuracy of ±10 percent in range and ±1 degree in azimuth and elevation. This method is capable of distinguishing between signals from craft only 10 degrees apart in azimuth and is amenable to a PPI type of presentation. The other two methods devised thus far have some virtues but appear to offer less dependability and accuracy.

CONCLUSIONS

Experimental data indicate that the potential value of using gamma radiation for stationkeeping purposes at short ranges warrants a more detailed investigation. The source of radiation is small, lightweight, maintenance-free, and has known properties capable of calibration. The radiation does not interfere with and is not affected by electronic equipment. It is essentially nonjammable and nondetectable beyond the design range. Gamma radiation undergoes negligible attenuation during propagation through an atmosphere varying in density, temperature, and pressure. These virtues recommend its use for an all-weather formation-control system.

RECOMMENDATIONS

In view of the urgent military need for an all-weather, day and night, short-range stationkeeping system, with possible applications to other types of military and commercial use, it is recommended that an expanded effort be directed toward the expeditious development of a gamma guidance system.

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PROBLEM ANALYSIS

Helicopters engaged in close-order maneuvers require a formation-control system that will maintain specified clearances and orientations among the craft. For this study, a minimum clearance of 60 feet and maximum practical range of 1000 feet were used, based upon the constraints of danger of collision and the largest safe radiation source possible. An acceptable system is considered to be one that will give reasonably accurate information as to range, azimuth, and elevation, under all conditions of weather and darkness. The system should be simple, compact, lightweight, and inexpensive. A desirable feature would be the ability of a second craft to assume command upon loss of the leader.

METHODS OF SOLUTION

Basic to any gamma gaging system are a radioactive source, a radiation detector, and a presentation device. Cobalt-60, a readily available gamma emitter, with two distinctive response peaks of high energy and a half-life of 5.3 years, is typical of several suitable isotopes. Scintillation detectors are recognized as most efficient and versatile devices, and usually contain a scintillating phosphor, such as sodium iodide, which is optically coupled to a photomultiplier tube and provided with output amplification. The output voltage is proportional to the rate of disintegration of the source, which is a known rate for any isotope and is a function of the distance from that source.

Three methods of using these basic components were devised and evaluated.

BEAM-RIDER METHOD

A beam-rider system consists of a small radioactive source contained in a lead shield provided with a collimator (figure 1a), and located on the guiding helicopter. A conical beam of radiation of the desired characteristics is directed toward the helicopter following the beam, or several beams could be provided for guiding several craft. Each following craft is equipped with a large-area sensitive detector whose count rate is an accurate measurement of range. This detector is surrounded by four less sensitive detectors, two of which are diametrically opposite horizontally, and the remaining two diametrically opposite vertically (figure 1b). Any detector moving into the penumbra of the beam (figure 1c) produces a lower count rate than its counterpart, providing a difference signal which can be the input to an automatic pilot or warning device calling for correction of course. Figure 2 is a graph of experimental data showing the correlation of detector count rate versus source distance. Figure 3a depicts the results of moving two detectors in and out of a beam collimated to provide a "gray" area of signal that diminishes with distance from the beam's axis. Figure 3b represents the difference between the right and left detector signals at each deviation from the axis.

ECLIPSE METHOD

The eclipse method uses an unshielded omnidirectional gamma source in each helicopter. This source is located as remotely as possible from personnel and detectors. To avoid a saturated condition, a small amount of shielding is interposed between the source and the detectors. Two detectors are mounted diametrically opposite on a rotating platform, with a small shield interposed between detectors (figure 4). When aligned with the source in another craft, the front detector reads the full intensity, while the eclipsed detector reads much less. When this difference signal reaches a maximum, the two detectors are precisely in line with the source, and this signal is a function of the distance to that source.

Figure 5 is a graph of experimental data showing the correlation between detector count rate and azimuth or elevation of the source. Figure 6 demonstrates the ability to separate equally strong signals from three craft at 10-degree intervals in azimuth. Figure 7 depicts a "worst case," where one craft is nearby and two others are detected through the high noise-level.

COLLIMATED-DETECTOR METHOD

The collimated-detector method (figure 8) uses an omnidirectional gamma source on each craft, and a single collimated scintillation detector as a scanner. The detector provides a maximum signal when directed toward the source, and the count rate is a measure of the distance. Figure 9 shows the count rate resulting from rotating a detector with respect to a signal source. The angle of separation between two or more signals depends upon the length, thickness, and shielding material of the collimator.

COMPARISON OF METHODS

Of the three methods, the eclipse method appears to hold the most promise. It provides better accuracy in azimuth and elevation and it is much lighter in weight because it needs much less shielding.

The beam-rider method presents serious problems of reliability, inasmuch as turbulent air or an emergency maneuver of the guiding craft could suddenly deprive the following craft of a rideable beam. The beam-rider system is also the heaviest of the three and requires five detectors with duplicate electronic circuits. It is capable of providing information pertinent only to the guiding craft, none pertaining to other craft in the formation.

The collimated-detection method has the simplest electronic configuration, but depends upon dense shielding to collimate the detector. Consequently, as the accuracy increases, the weight of the system also increases. If altitude information is not required, this detector can locate other craft in azimuth and range by rotation in a horizontal plane, and can produce the signal for a PPI type of presentation. Where altitude information is required, it must scan vertically as well as horizontally, and the dwell time required to provide high enough counting statistics becomes critical. This problem also applies to the eclipse method, and can be better understood through the mathematical analysis given in appendix A.

Variable high background radiation resulting from jamming attempts, fallout accumulation, or radioactive mineral deposits, can present a serious problem to the beam-rider and the collimated-detector methods, as they depend upon a single detector for range information. Gating or discriminating devices can be employed, but they add to the complexity of the system. Since the eclipse method uses a difference signal between two detectors subjected to the same background, it is unaffected by variations in this background, except that the signal must rise above the background noise. This problem might be solved by applying some collimation or light shielding to raise the difference signal above the surrounding noise.

D I S C U S S I O N

The mathematical analysis presented in appendix A and the experimental data accumulated in the laboratory setup indicate that the application of gamma radiation as a sensing signal for short-range stationkeeping is basically sound, and needs only a concerted development effort to advance it to the hardware stage. While some problems and limitations will be encountered and compromises will be required, there are no foreseeable reasons why a gamma guidance system should not prove effective and far more dependable than current methods, where short distances are involved.

The technology of the propagation and detection of gamma radiation is well advanced, and a simple straightforward engineering approach should produce reliable equipment suitable for service requirements. The "transmitter" can be an encapsulated cobalt source, perhaps 1/2 inch in diameter and weighing an ounce or so. Scintillation detectors have been ruggedized and miniaturized to the extent that the crystal, photomultiplier, high-voltage power supply, and amplifier can be contained in a cylinder 2-1/2 inches in diameter by 7 inches in length. Scanning and presentation devices for radar applications can be adapted readily for the new system.

The presence of a sizable source of radioactivity presents no more hazard than that presented in the day-by-day work of nuclear laboratory personnel. Proper maintenance procedures would need to be observed, but built-in safeguards could reduce the risk of even minor radiation exposures.

It is concluded, therefore, that early realization of an effective formation-control system for close-order maneuvers is entirely feasible.

To reap full benefit from the work already done, and to take advantage of the radiation sources and laboratory instrumentation setup, it is recommended that the current investigation be continued. Several areas of study and experimentation are indicated:

1. As the eclipse method shows the most promise, the optimum size and shape of shield to be interposed between detectors, the geometry and spacing of the elements, and the means for raising the intensity of the signal above that of the background noise, should be determined.

2. Data must be accumulated on the reliability of the eclipse system under a variety of operational and emergency conditions.

3. Investigations must be made to determine the best means of adapting scanning and presentation techniques to the gamma guidance system.

4. Safeguards must be built into the system to protect the crew, passengers, maintenance personnel, and the public from the potential hazards of the radioactive material in this device.

George E. Wilcox

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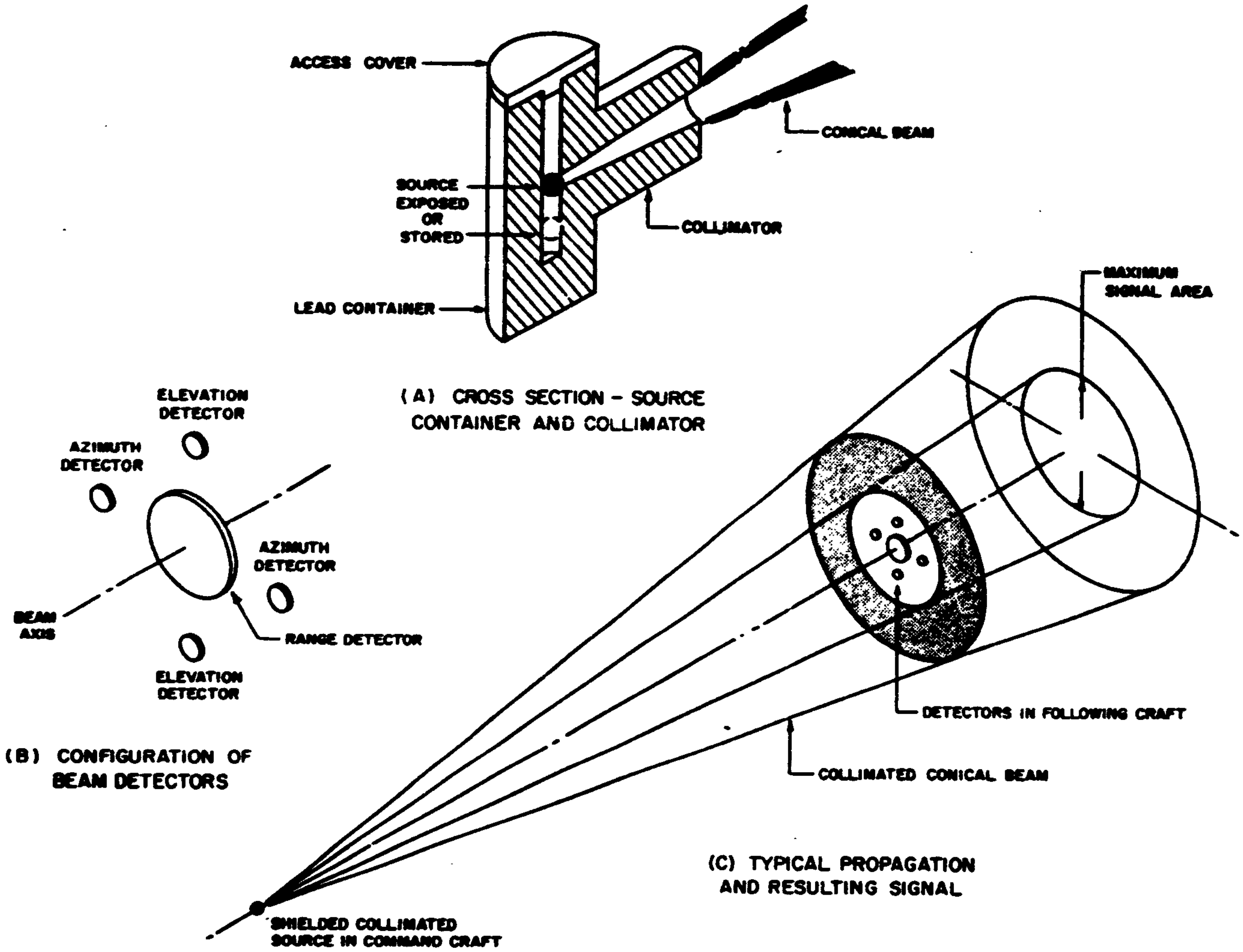

FIGURE 1 - Beam-Rider Method

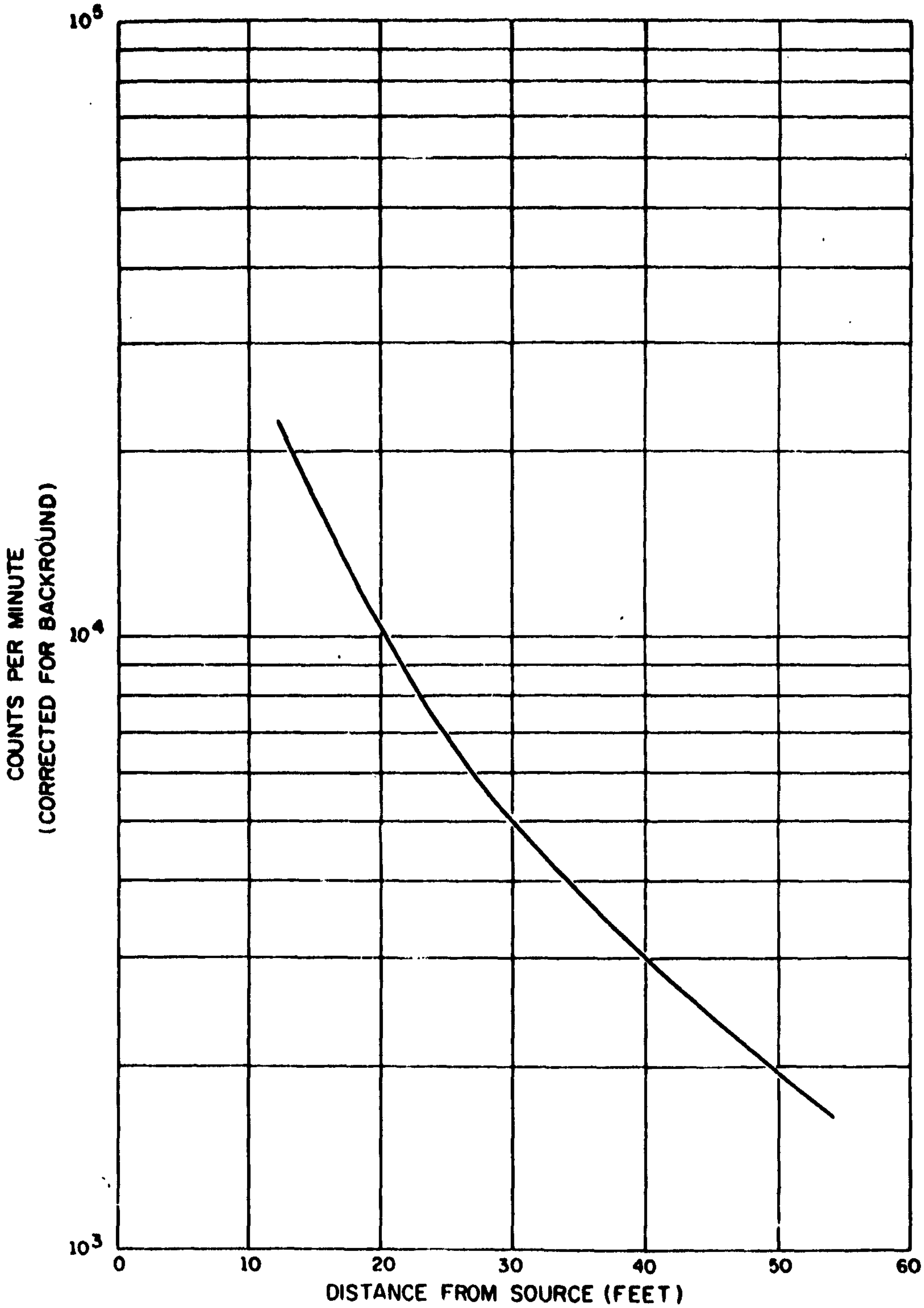

FIGURE 2 - Detector Count Rate Versus Source Distance (Beam-Rider Method) (5-Millicurie Cobalt-60 Gamma Source)

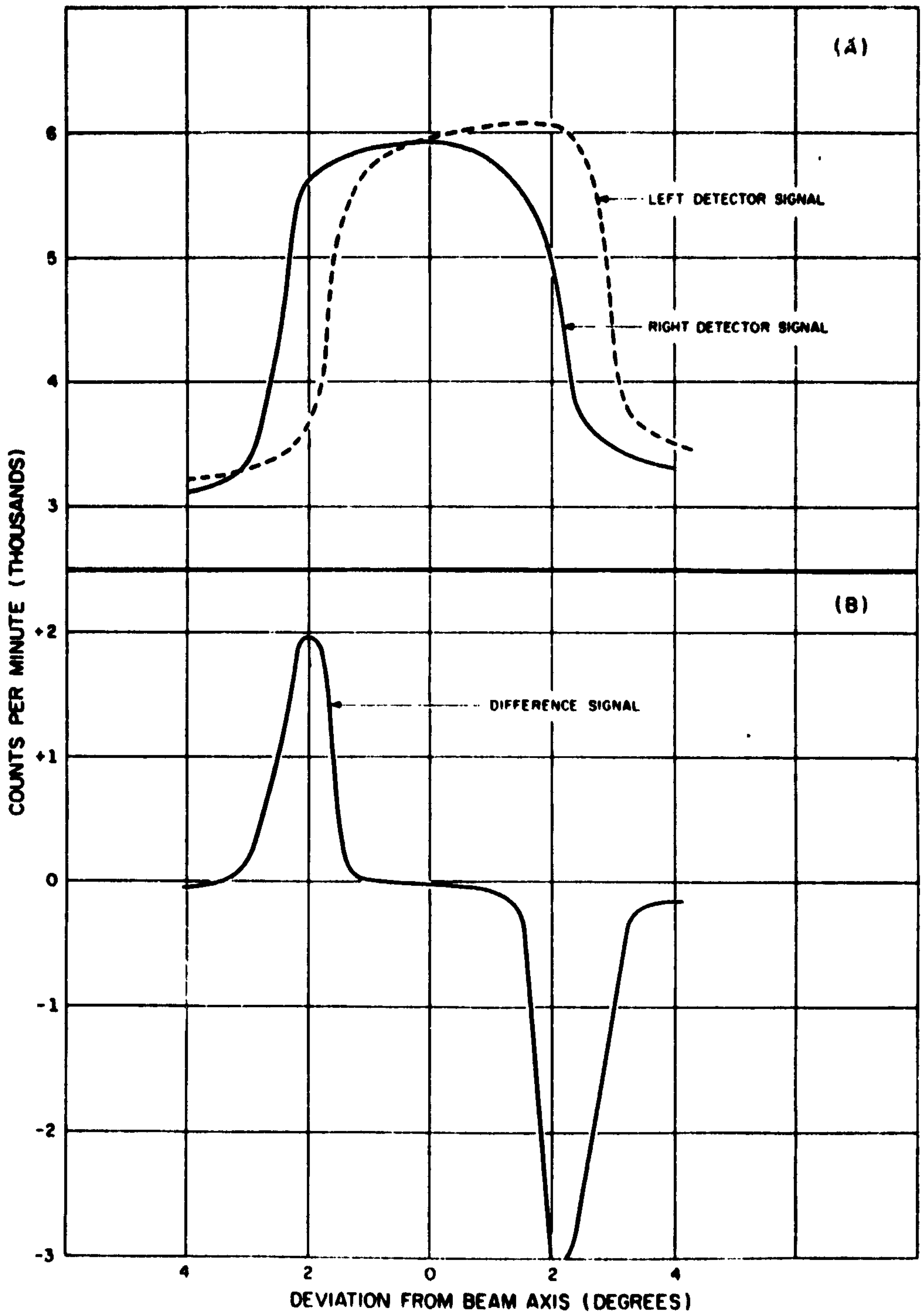

FIGURE 3 - Signal Versus Azimuth or Elevation of the Signal Source (Beam-Rider Method)

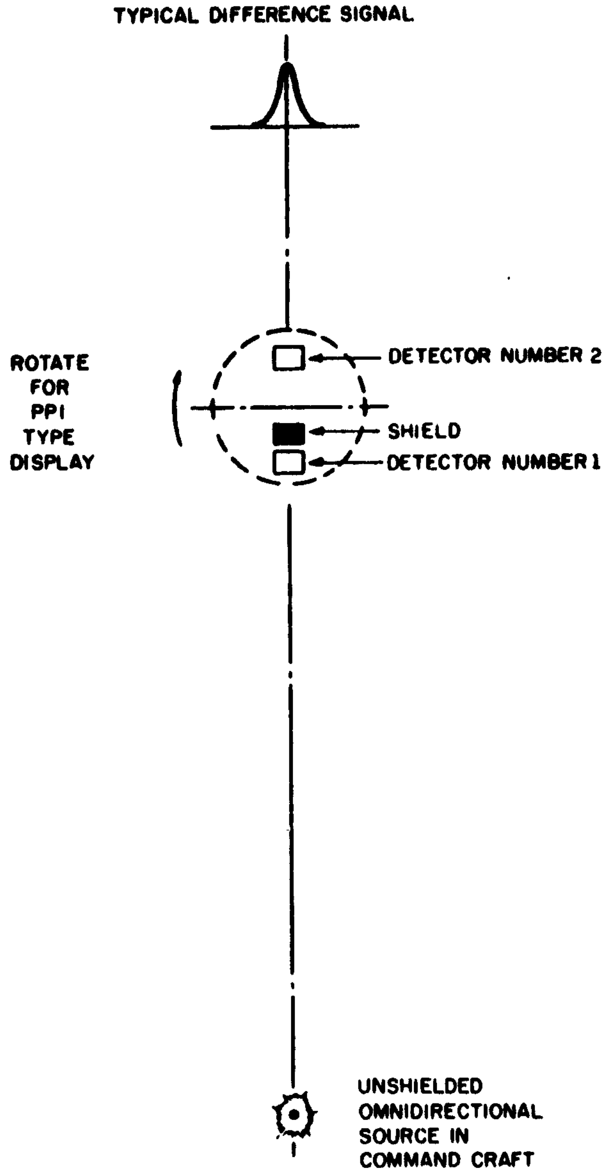

FIGURE 4 - Eclipse Method - Physical Arrangement

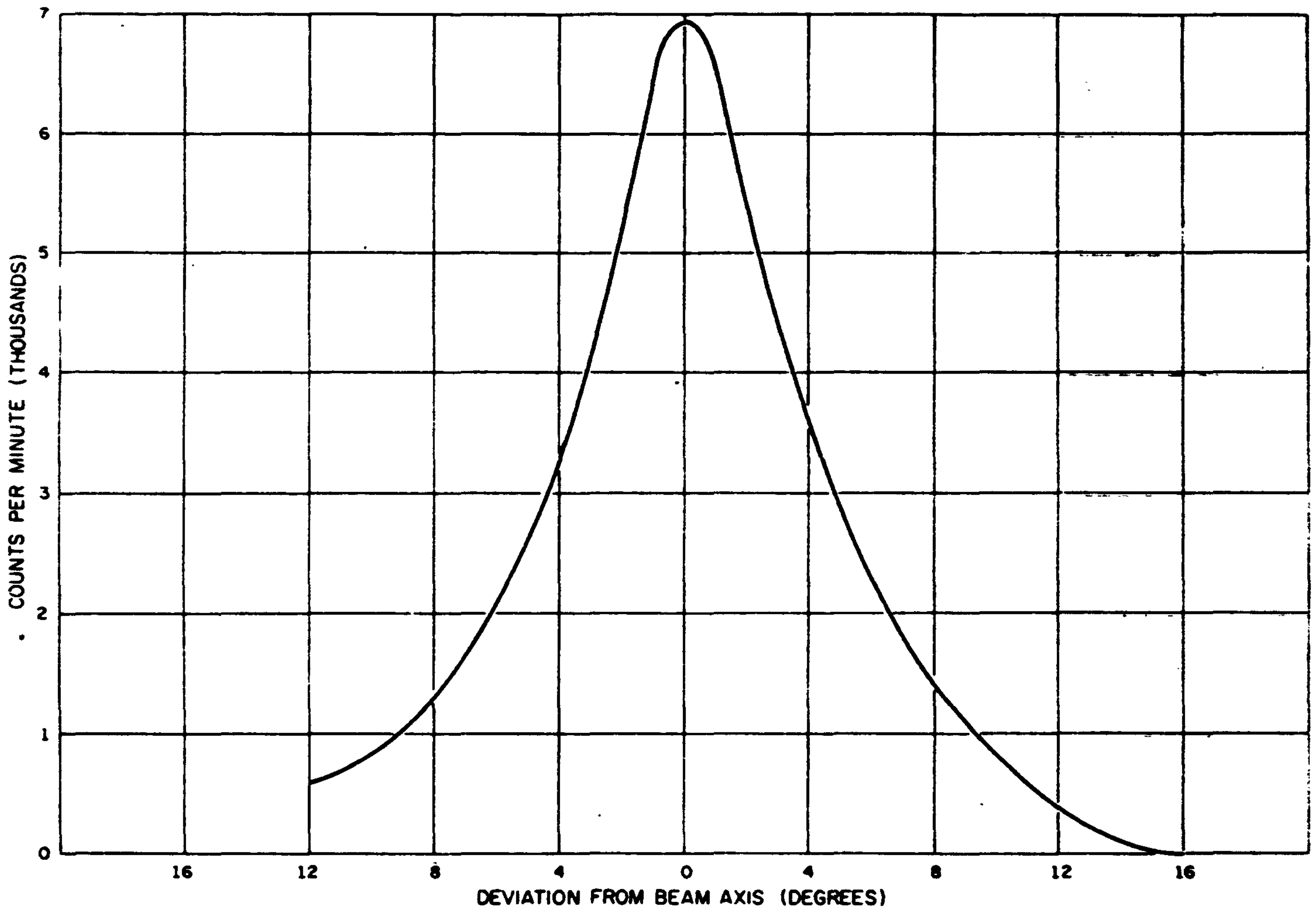

FIGURE 5 - Detector Count Rate Versus Azimuth or Elevation of the Signal Source (Eclipse Method)

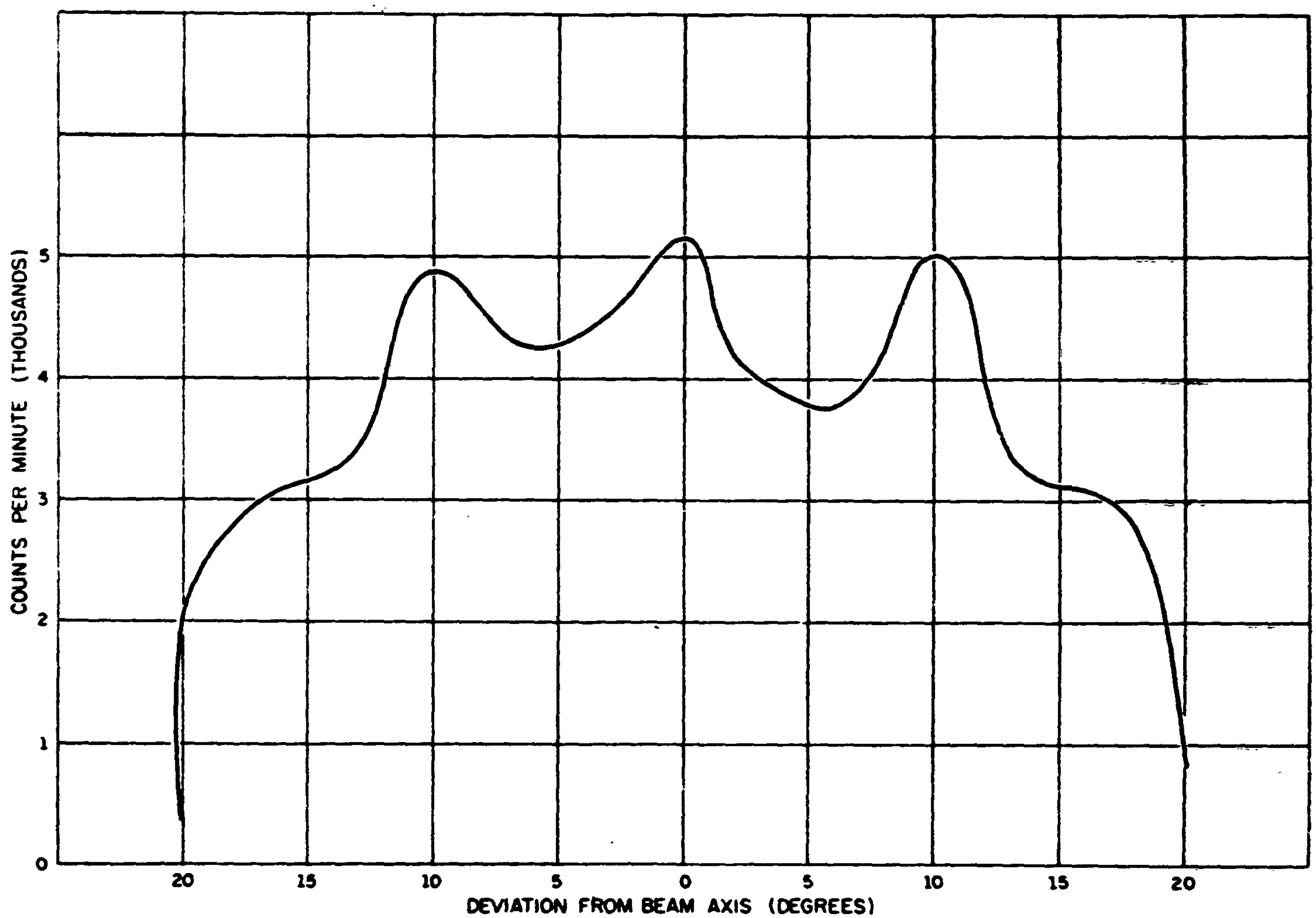

FIGURE 6 - Three Equal Signal Sources at 10-Degree Intervals (Eclipse Method)

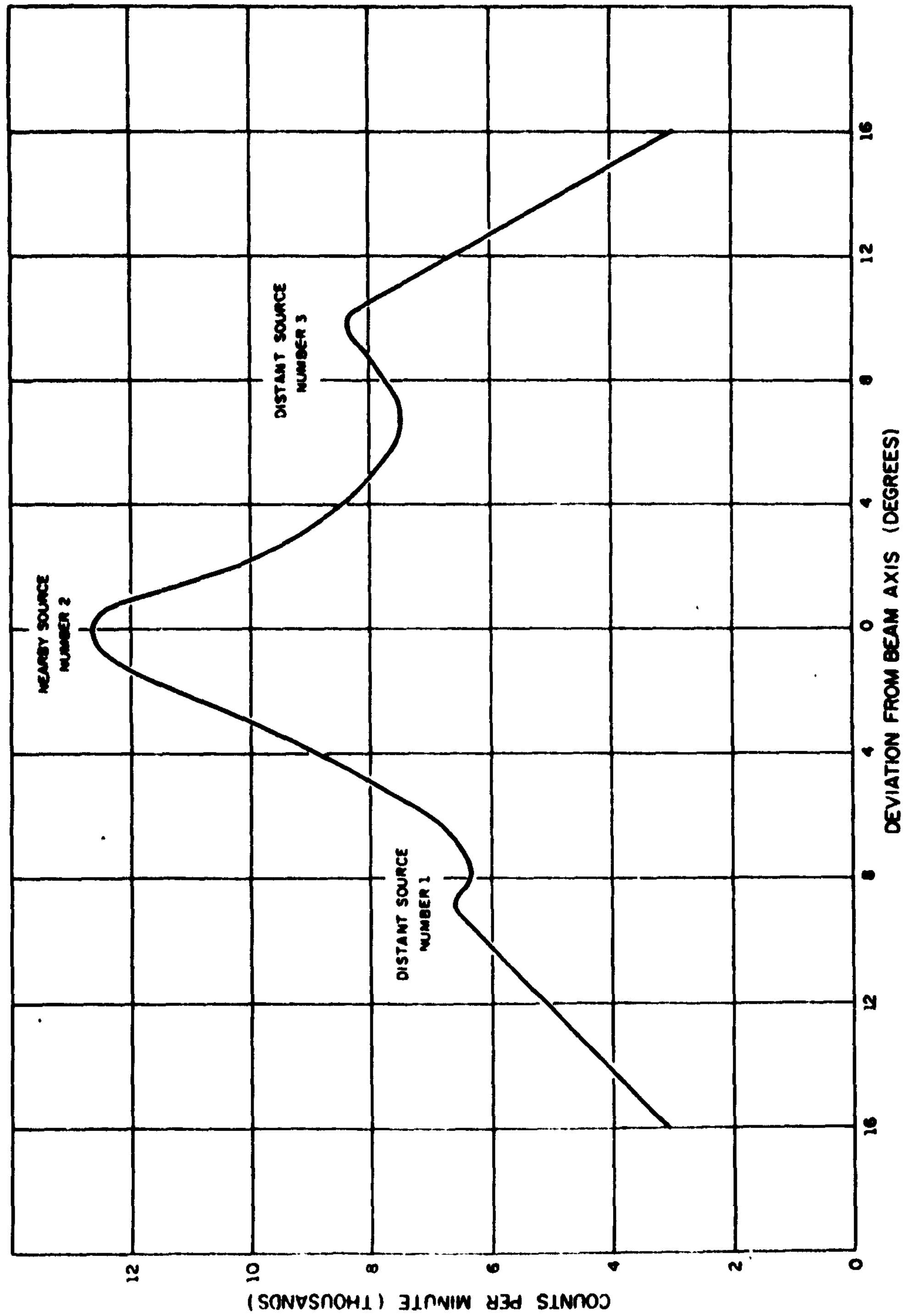

FIGURE 7 - Three Unequal Signal Sources at 10-Degree Intervals (Eclipse Method)

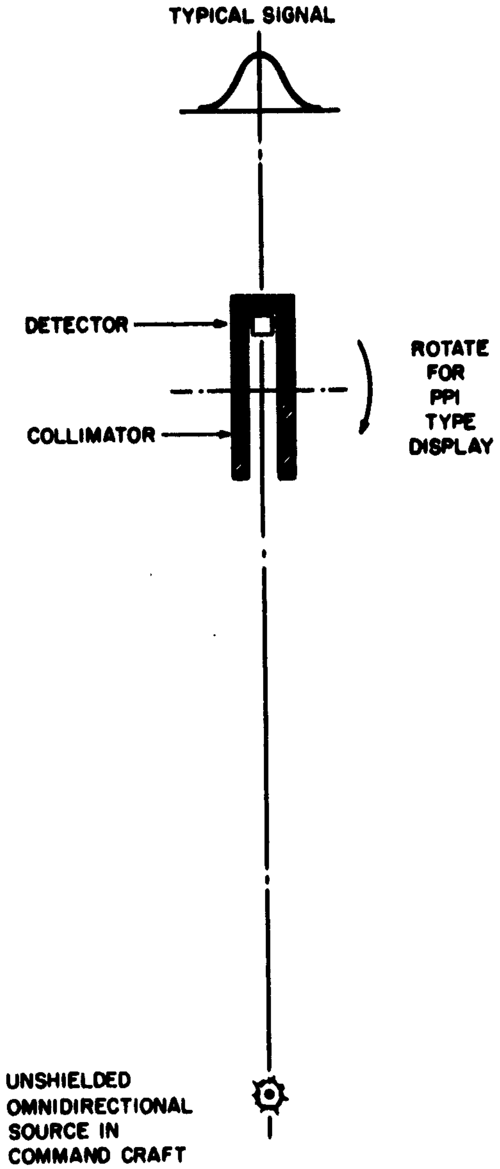

FIGURE 8 - Collimated-Detector Method - Physical Arrangement

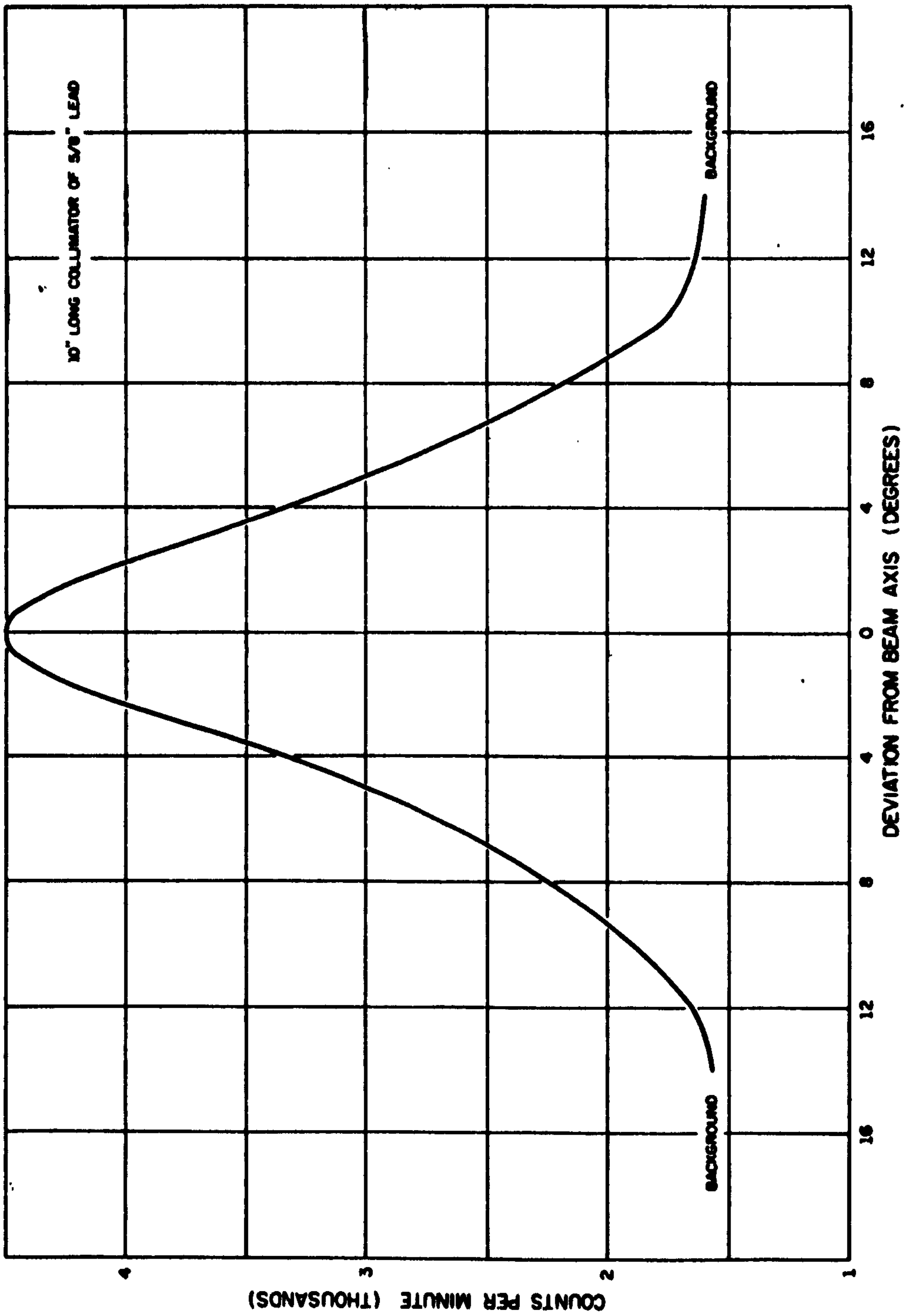

FIGURE 9 - Count Rate Versus Azimuth or Elevation of the Signal Source
(Collimated-Detector Method)

APPENDIX A

MATHEMATICAL ANALYSIS OF GAMMA RADIATION AS A SENSING SIGNAL FOR SHORT-RANGE STATIONKEEPING

GAMMA PROPAGATION

Basic to any gamma gaging system are a radioactive source, a radiation detector, and a readout device. In the helicopter formation-control system, it is proposed to utilize a moderate amount of an isotope such as Cobalt-60, which has a half-life of 5.3 years and therefore holds its calibration over a considerable period of time. The gamma photons emitted from the source travel in straight lines until they strike atoms of a material, such as air, at which juncture they react characteristically. In a vacuum, however, no scattering occurs and the number falling on a section of a sphere at radius R from the source is:

$$I_R = I_o/4\pi R^2 \qquad (1)$$

where

I_R = the radiation flux at radius R (particles per square centimeter per second),

and

I_o = the total emission from the source (particles per second).

Equation (1) is strictly accurate only in a vacuum, and is modified by an attenuation factor in other media. However, since the attenuation factor is considered as practically unity for propagation through air, or even clouds, for purposes of this analysis, equation (1) can be used as shown.

The signal output of a detector at a distance R from a source is:

$$S = AEI_R \qquad (2)$$

where

S = signal output (counts per second),

A = effective area of the detector (usually the projection of the volume on a plane perpendicular to the direction of the source),

and

E = efficiency of conversion of photons to electrons.

Substituting the value of I_R from equation (1):

$$S = AEI_o/4\pi R^2 \qquad (3)$$

where A, E, I_o, and 4π are constants. Thus, the signal S is inversely proportional to the square of the distance R between the emitter and the detector, and subject to degradation through variations in absorption, scattering, and other attenuating factors which are not always predictable.

The intensity of a radiation source is measured in disintegrations per second. Substituting, therefore, the value of 1 curie (3.7 x 10^{10} disintegrations per second) for I_o of equation (3):

$$S = (AE \times 3.7 \times 10^{10})/4\pi R^2$$

$$= (2.94 \times 10^9 \ AEC)/R^2 \qquad (4)$$

where C is the source strength in curies.

Extraneous radiation from other sources, such as cosmic rays, mineral deposits, and fallout could influence this result unpredictably. The system used must therefore attenuate stray background signals.

STATISTICAL DEVIATION

After eliminating the influence of background, the signal S in equation (4) is a measure of a flux intensity that is a pulse counting rate of a random emission, and is subject to statistical deviation. From the theory of distribution of such measurements, the probable error in the total count is the square root of that number. The total count is the rate S multiplied by the time in which it was measured, or C = St; and the probable error in the total count is:

$$\Delta_t = \sqrt{C} = \sqrt{St}$$

The probable error, then, in the rate measurement S is:

$\Delta_t/t = \sqrt{St}/t = \sqrt{S/t}$, and the percentage probable error in S is:

$$(\Delta t/t)S = 100/\sqrt{St} \qquad (5)$$

From equation (5), it is obvious that system accuracy improves with an increase in counting rate and with the duration of time that is the basis for forming the average rate.

PRACTICAL APPLICATION

In practical terms, after having devised a detector as large and as efficient as feasible, its degree of accuracy is dependent upon the strength of the radiation source and the dwell time of the detector while aimed toward the source.

Substituting in equation (4) realistic design parameters for an eclipse-type device:

$$S = (2.94 \times 10^{9}\ AEC)/R^{2} \qquad (6)$$

where

A = axial section of a 2-inch-diameter by 2-inch-long crystal = 25.8 square centimeters,

E = conversion efficiency of crystal = 0.8,

C = curie strength of source = 0.25, and

R = 200-foot distance between helicopters = 6100 centimeters.

Then:

$$S = (2.94 \times 10^{9} \times 25.8 \times 0.8 \times 0.25)/3.7 \times 10^{7} = 410 \text{ counts per second,} \qquad (7)$$

and the percentage of probable error for a 1-second count, using equation (5), would be:

$$100/\sqrt{SE} = 100/(\sqrt{410 \times 1}) = 100/20.2 = 5 \text{ percent}$$

These results represent only the variation in signal that can be expected with a 1-second dwell time, and become worse rapidly as the time allowed to analyze the signal decreases. Fortunately, as the danger of collision increases with decrease in range, the statistical accuracy rises exponentially.

OVERALL ACCURACY

The preceding discussion covers only the accuracy of the signal output of the detector. The manner in which this signal may be used in a control system introduces other inaccuracies. It seems safe to state that the error might be double that derived above, resulting in an ultimate read-out accuracy within ±10 percent of the actual range.

The nature of the eclipse method, wherein a reversal of the sign of the slope of the difference signal is used, provides a much higher accuracy for determining azimuth or elevation in terms of degrees of deviation. Laboratory experiments disclose a deviation of less than ±1 degree in the indicated direction of the source, even in the presence of other nearer sources.