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AERIAL MONITORING SYSTEM STUDY

GENERAL DYNAMICS | FORT WORTH

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This document is submitted as the final report of the Aerial Monitoring System Study conducted for the Office of Civil Defense under Contract Number OCD-OS-62-275.

ABSTRACT

Flight procedures and design requirements for instrumentation for making aerial radiological surveys are developed in this study. It is concluded that an aerial monitoring system designed with presently available components is not only feasible but also practical to monitor fallout from nuclear incidents. A recommended system which was selected on the basis of cost and response time is described in considerable detail.

Radiation fallout patterns, expected number and location of burst points, wind effects, and local anomalies are considered in connection with aircraft range, speed, and basing constraints to develop flight procedures for making a survey of the U.S. or of fallout of a single burst. Sensor design is based upon the capability to measure ground radiation levels between 1 R/hr and 1000 R/hr from altitudes above 1000 feet in the presence of airborne activity.

Facsimile, teletype, and digital systems are considered for the data system to provide the national center with geographical position and time referenced radiological data with which contour maps can be constructed.

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1. INTRODUCTION

The United States is now faced with the threat of a large scale nuclear attack and may continue to be for many years. If an attack does come, the measure of our ability to survive and recover will be the courage with which we appraise the dangers, and the vigor with which we act to prepare for them.

Although many people and large quantities of physical goods will be destroyed immediately by blast and heat radiation, a certain percentage, hopefully large, will survive. The ability of our nation to recover will depend, to a large degree, upon the capability of the people who survive the initial dangers to overcome the effects of nuclear radiation resulting from the fallout caused by the nuclear bursts.

Theoretical calculations to determine the distribution of short term fallout usually assume that the wind blows in just one direction at a given speed. Under such conditions, radioactive fallout will tend to settle in a cigar-shaped pattern, with radiation intensity diminishing in the downwind direction and toward the outside edges. In practice, however, winds at different altitudes move in different directions at different speeds. So actual patterns of fallout tend to be highly irregular. This means that it is not safe to predict radiation levels as an estimate of hazard in an area. The only sure answer is to measure the radiation intensity.

The purpose of this study, according to the contract, is to "develop flight procedures and establish the design requirements for instrumentation needed for large area radiological surveys, using drone, military or commercial aircraft in the 150 to 350 knot speed range. In order to identify optimum operational procedures and devise the integrated system to accomplish the required surveys, the contractor shall establish an analytical model which will permit evaluation of various flight procedures; data collection, processing and display methods; individual system components and combination of components; and the interaction of these factors in the complete system."

To be effective the airborne system must determine the amount of radiation on the ground from measurements taken in the air, process the data, and transmit it to a ground station in a usable form. Thus, consideration is given to airborne data transmission and processing techniques and instrumentation, as well as to sensor design requirements. The airborne readings may be taken in the presence of an air burden that may be quite intense.

Based upon such factors as expected location of bursts, time history of bursts and fallout from bursts, meteorological data and fallout characteristics, flight paths and survey patterns are determined which efficiently gather the required information.

As opposed to a ground monitoring system where fixed sensors are deployed in advance of a nuclear incident, the capability to choose the characteristics of the monitoring points (dose rates or monitoring location) is exploited in the aerial system. Operational and design parameters relating to the quality of the data with respect to the amount of detail and accuracy are based upon assumptions regarding the needs of the user. Design requirements are made on the basis of systems cost and response time.

Recommended systems are detailed in Section 2. This includes a description of the components needed and their method of employment in the system, as well as the quantity required and the cost. The remainder of the report is devoted to the formulation and analysis of the survey problem, and describes how and why the recommended systems were chosen.

Section 3 contains a discussion of the important factors which cause variations in the area and shape of fallout patterns from ground bursts of nuclear weapons. The distribution of isodose rates and the formation of hot spots inside the area bounded by the 1R/hr dose rate line are considered. A sample distribution of fallout patterns over the U.S. relative to an assumed target system is given in Section 4 and flight procedures to monitor fallout from a single burst and for multiple bursts are developed in Section 5. In Section 6, the crew-radiation-shielding problem is examined. Section 7 contains the technical details associated with estimating fallout radiation intensity on the ground from measurements made in the air. The design of a practical airborne detector is given and a sensor system for use in contaminated air is described.

A detailed description of available components for processing and transmitting data from the survey aircraft to the national center is given in Section 8. Facsimile, teletype, and digital systems are included. Section 9 contains estimates of investment and yearly operating costs of candidate survey aircraft and Section 10 gives cost effectiveness trade-offs and comparisons which are used to determine a preferred system. Conclusions and recommendations resulting from the study are given in Section 11.

2. TECHNICAL DESIGN OF AERIAL MONITORING SYSTEM

Two general types of aerial monitoring systems have been considered in the study. One, called the "Flock" system, consists of a number of low flying survey aircraft, each carrying survey apparatus and transmission equipment to relay the data to ground receiving stations. The other, called the "Covey" system, consists of low flying survey aircraft and a high altitude control or Director aircraft which hovers in the air within data transmission range of the survey aircraft assigned to it. The Director aircraft receives the data from the survey aircraft, processes it, and transmits the results to ground receiving stations. Based upon analyses performed in later sections of this report, the "Flock" system is the recommended system and the "Covey" system is the alternate or second choice.

2.1 Recommended System

This section gives a detailed description of the elements of the recommended system and an operational procedure for its use. The system consists of survey aircraft, the radiation detector system, and the entire data link from the detector system in the survey aircraft to the data display device at the National Center.

2.1.1 Survey Aircraft

The comparative evaluations, based on cost, made in Section 10 resulted in the selection of the Beech G18S as the preferred aircraft to be used for low altitude data collection flights with either the Flock or Covey System. Tho Howard 500 (see Figure 8.4) although more expensive, may be more suitable for the survey airplane if factors such as crew comfort, reliability from inflight maintenance, alternate mission capability, etc., are considered.

The Beech 18S is a low wing airplane with a 9,700-pound gross weight (see Section 9). It is a twin reciprocating engine aircraft with a low altitude (sea level) flight capability of 1470 miles range at 155 mph, or 1170 miles range at 195 mph. These ranges are available with a payload of 2000 pounds. The airplane can be operated from and maintained at a large number of small civilian airports where the airplane will normally be based. The crew consists of pilot, copilot, and data plotter.

2.1.2 Radiological Sensor

The fallout dose rate at ground level is to be inferred from the γ-ray flux measured at the position of the survey aircraft. Detector requirements are determined by the flux obtaining at the detector and the background level. It is shown in Section 7 that the necessary information may be obtained by taking the difference between simultaneous measurements of (signal + background) and background alone.

Properly shielded and collimated scintillation detectors are optimal in this service. An "upward-looking" detector measures background alone, while a "downward-looking" detector responds to signal plus background. This design is based upon a Monte Carlo prediction of scatter effects at the altitude under consideration (see Appendix C). Ratemeters are proposed as convenient means of obtaining analog information which may be fed directly into the system computer.

Detailed consideration of the expected γ-ray fluxes from fallout, contaminated air, and natural background enables calculation of detector requirements. For example, it is found that detectors with a sensitive area of 1.25 cm^2 and an acceptance angle of 1.21 steradian are appropriate for use at 2200 feet for survey over ground level dose rates in the range 1 R/hr to 1000 R/hr. The accuracy of the measurement of γ-ray flux from fallout is 10% or better in this range. These calculations and conclusions are discussed in 7.2.2.

The weight of a complete detector system (two shielded detectors and electronic adjuncts) will be approximately 200 pounds.

Calibration and standardization of the detectors are considered; it is found that both processes are reasonably simple.

2.1.3 Data System - Facsimile

The Flock System is used to designate a group of survey aircraft operating independently of each other. Each aircraft has a data collecting, data processing, and air-to-ground data transmission system.

A cut-away sketch of equipment installed in the cabin of the Beech 18S aircraft is shown in Figure 2.1. This location of the equipment is tentative as an aircraft weight and balance study may require shifting of equipment.

The dual sensors are shown mounted in a cabinet with sealed cones in the line-of-sight of the detector opening. The section of the fuselage that the sensor looks through has a removable port which will be open during the survey. A roll of aluminum foil which is advanced during the survey covers the opening to provide a clean surface for the sensor to look through.

The data system block diagram shown in Figure 2.2 indicates the functions of the various components. Parameters measured in the aircraft are (1) the altitude above the terrain, (2) dose rate in roentgens per hour, (3) time in terms of a preselected reference time, and (4) latitude and longitude of the point over which the dose rate was measured.

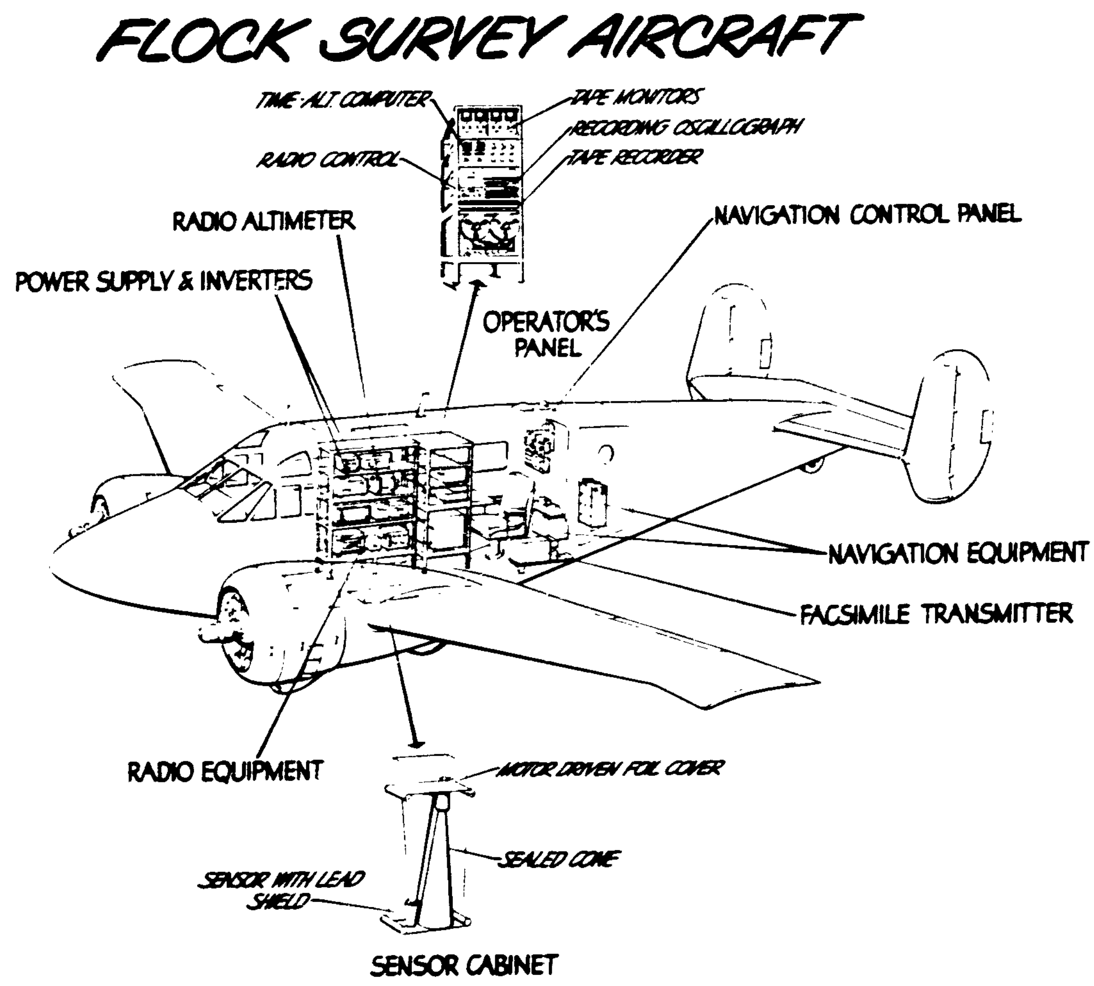

Fig. 2.1 Beech 18S as a Survey Aircraft

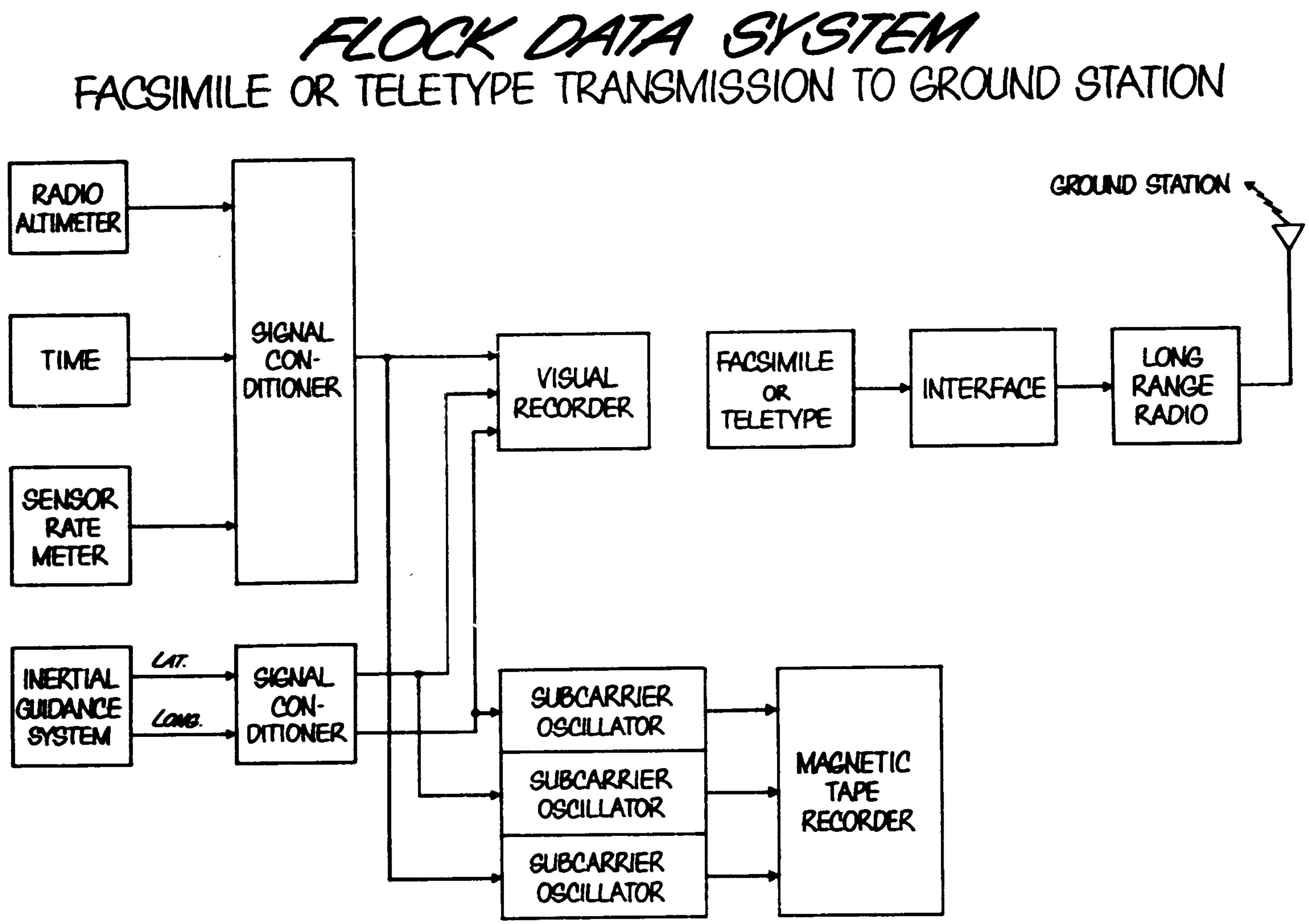

Fig. 2.2 Recommended Data System

o Navigation System -- The LN-3 inertial guidance system proposed by Litton (see Section 8.3.3) is recommended to give the geographical coordinates of the point over which the dose rates are measured. This system is in use in the F110 aircraft. A Bendix AN/ASN-39 computer provides manual updating capability to the LN-3 system and a backup navigation capability in event of a platform failure.

o Radio Altimeter - The RCA Radio Altimeter (see Section 8.3.4) appears to be the best unit in terms of cost, weight, and accuracy to measure altitude above the terrain. The unit may require modification to provide an output voltage proportional to the altitude.

o Dose Rate Output - The intensity of the radiation on the ground measured in terms of R/hr will be the difference between the outputs of the two detectors discussed in Section 2.1.2, properly corrected for altitude and time.

o Time and Altitude Computer - The effect of time and the effect of altitude on dose rate are logarithmic relationships. Computations involving these relationships can be made by a small computer (see Section 8.3.5.2) made up of commercially available components. Altitude and time outputs may be used to drive logarithmic amplifiers coupled with voltage dividers to make the required corrections. The computer will have controls for setting in reference time, time of the initial burst, and time for the final burst.

o Data Recording — The corrected dose rate and the geographic coordinates are processed by a signal condition into a form compatible with a visual strip recorder. The geographic coordinates are processed into coarse, medium, and fine by a synchro repeater to permit the reading of position to the neartest minute of arc. The data are displayed on a visual strip recorder, making a permanent record. The data are also recorded on a magnetic tape as a backup system.

o Data Processing — The data plotter, using data from the visual recorder, will manually plot dose rates in 1, 3, 10, 30, 100, 300, and 1000 R/hr steps versus geographic coordinates on an area map. The area maps containing the data plots will be transmitted by facsimile to one of the Civil Defense Regional Headquarters.

o Data Transmission — The area map with dose rate readings plotted manually by the data plotter will be inserted in the facsimile data transmitter. The facsimile transmitter (see Section 8.3.2.2) converts the map to an amplitude modulated (AM) signal by a phototube scanner. The AM output of the facsimile transmitter is converted to frequency modulation (FM) by a signal converter (interface) so that the signal will be compatible with the long range radio. The long range radio signal is transmitted to the CD Regional Headquarters.

o Ground System – As the maps are received by facsimile at Regional Headquarters from the survey aircraft, the data will be replotted manually on a large area map. When all the data for the map of a preselected area have been received (this may require several facsimiles from the survey aircraft) contours will be drawn and the maps will be transmitted by facsimile to the Civil Defense National Center.

o Teletype Alternate Method – A monitoring system utilizing teletype data transmission from air-to-ground differs from the facsimile method only in that a teletype is used instead of a facsimile transmitter.

2.1.4 Monitoring Procedure

The basic monitoring system is designed to make equally spaced survey flights covering the U.S and the output is a presentation of the data in the form of radiation contours drawn on a national map. Radiation levels of 1, 3, 10, 30, 100, 300, and 1000 R/hr have been selected as sufficient for the user on a national scale (see Section 5.2). However, other values can be measured to adapt the system to satisfy the needs of a regional or local user. To aid in the construction of the contour maps, a dose rate reading is taken each time the survey flight path crosses the hot line (maximum point).

The survey flights begin approximately 12 hours after the last burst so that the fallout is essentially down. Delayed fallout, where debris is carried to great heights, may be much longer in coming down.

The U.S. is divided into rectangles each of which is assigned to two survey aircraft. These rectangles vary in shape to make them fit the area, but their dimensions are determined by the range of the aircraft and the fineness (separation of flight paths) of the survey. A set of rectangular areas compatible with the range of the Beech 18S making a survey at 50-mile intervals is shown in Figure 2.3. A rectangular survey pattern is used and each aircraft ends its survey flight at its base. The primary data collection portion of each flight is made in the north-south direction (see Section 5.3). A total of 55 Beech 18S aircraft are needed to make this surface survey with 50-mile spacing. An expanded view of one area of Figure 2.3 is given in Figure 2.4. This plot shows the location of the airport (away from expected targets), the monitoring flight path of the two survey aircraft, and a sample of the type of readings obtained. Dose rate contours for one fallout area have been drawn. Only monitoring points and radiation levels are shown for the other burst points.

In this example, the arrows show the direction of the survey flights, but the survey could be made in the opposite direction.

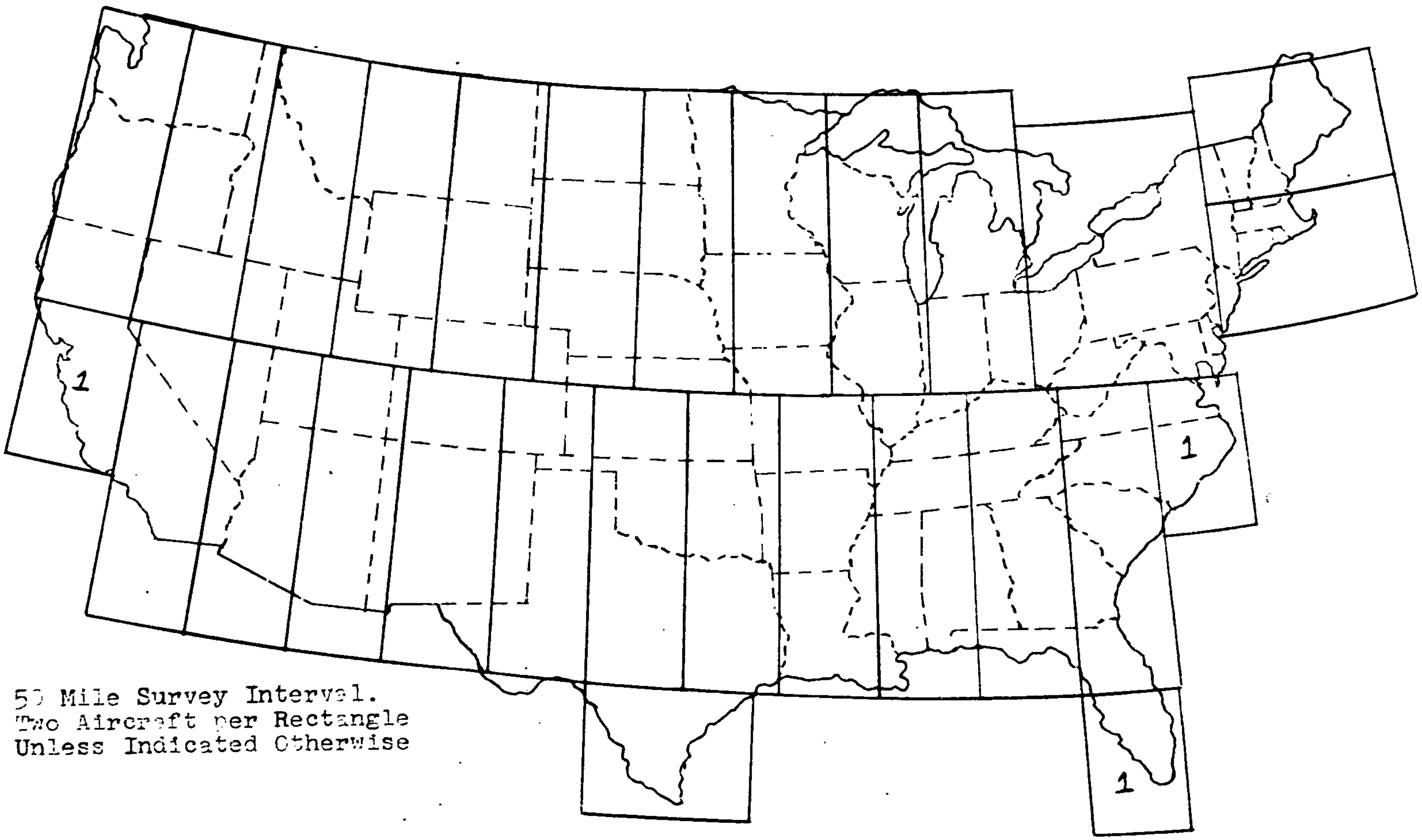

Fig. 2.3 Survey Areas for Beech G18S

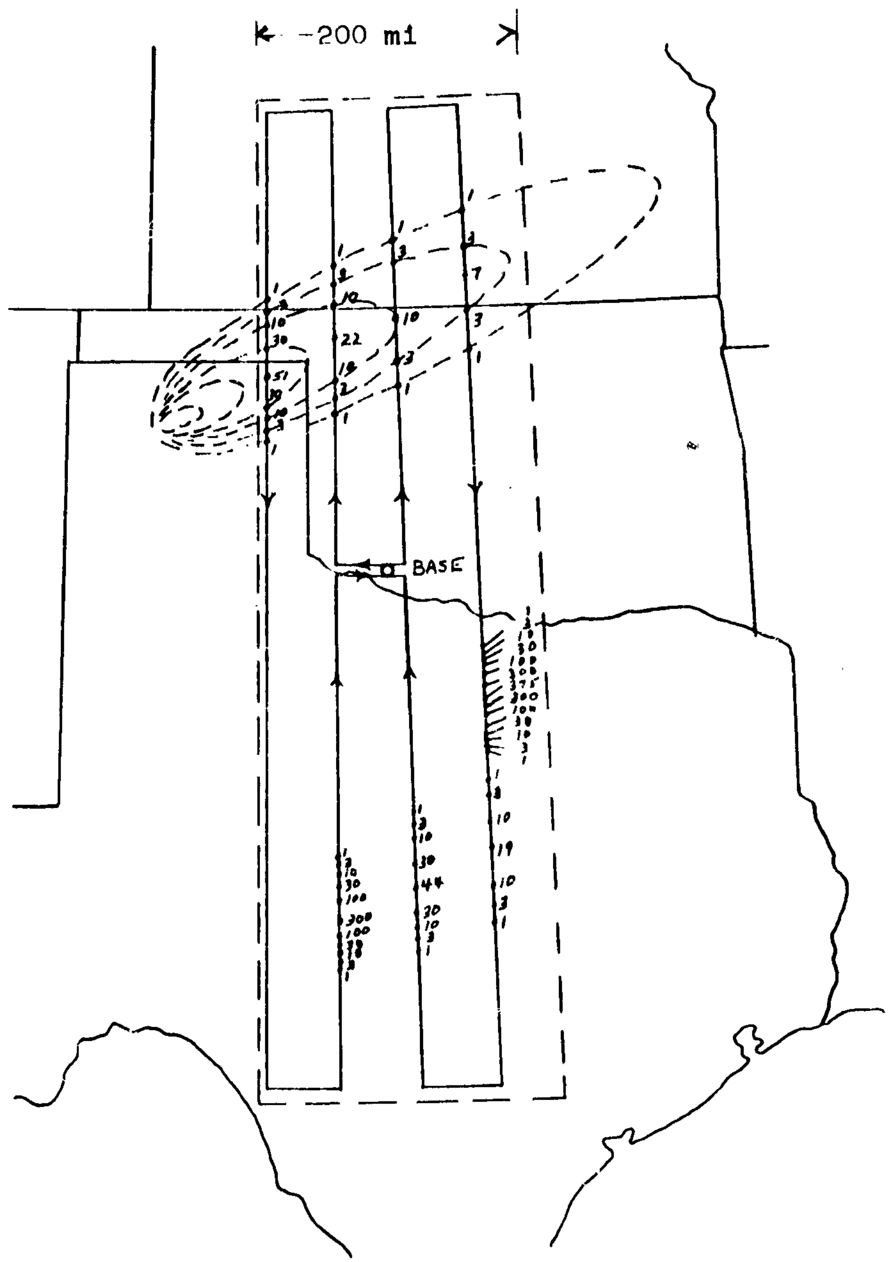

Fig. 2.4 Example of a Survey by Two Beech 18S

2.1.5 Operating Procedure

When the alarm is received that a nuclear incident has occurred, up to 12 hours are available to prepare the aircraft for flight. The crew consists of a pilot, copilot, and data plotter. The data system will be turned on and an operational check made of the complete data system. The insertion of the calibration source will provide a signal for an operational check of the radiation detector system. The preparation of the inertial guidance system for flight will provide data for checking that part of the data system. The radio altimeter has calibration signals which will provide data for checks of the altitude input signal. The time-altitude computer may be checked by changing the settings of the "time of burst" knobs on the control panel. The output of the sensors will be adjusted to zero with lead plugs inserted in viewing ports of the lead shield surrounding the sensors. The facsimile transmitter will be checked by transmitting to the Civil Defense Regional Headquarters. When the data system has been completely checked out, it will be placed on standby to wait take-off time. When take-off orders are received, the time and altitude computer will be energized. The reference time, the time of the initial burst, H_1, and the time of the last burst, H_2, will be set into the computer. The acquisition of the above data is a command and control function and the operational aspects of the monitoring mission involving command and control, authority for take-off, weapon burst data, etc., are not considered in this report. En route to the start of the first data run, the data system will be calibrated by inserting the standardized radiation calibration source into the sensors and recording the calibration data signals on the visual recorder and on magnetic tape. When the aircraft arrives at the first data run position, the visual recorder and the magnetic tape recorder will be turned on and the run started. A continuous record will be made during the data run. The motors that advance the foil port covering are turned on to ensure that the sensors are looking through an uncontaminated opening.

During the flight and continuing till he is finished, the data plotter manually plots the data on an area map. The data will then be transmitted to the ground station by facsimile. A magnetic tape recording, which will record continuous analog data, will be used as a source of data in event of failure of the visual recorder.

2.1.6 Estimates of System Costs

An estimate of the initial investment in equipment, plus the costs of establishing the system and the operating costs for a period of five years is given in Table 2.1.

Table 2.1

COST ESTIMATES

1.	Aircraft	
	o Beech 18S	119,715
	o Equipment Installation	65,000
	o 5 yr operating costs	53,253
2.	Equipment Available from Manufacturer	
	o Minneapolis-Honeywell Visicorder Model 906A	5,500
	o Collins Radio (HF) 618T	7,000
	o Westrex (Division of Litton) Facsimile AN/GXC-5	7,500
	o Sanborn-Ampex Magnetic Tape Recorder Mod. 2000	8,000
	o Elasco Inc. power supplies	3,000
	o Litton Industries Inertial Guidance System	90,000
	o RCA Radio Altimeter	6,000
	o Bendix ASN-39 Computer	7,000
3.	Equipment Available from Several Manufacturers Including GD/FW but requiring Modification or Special Fabrication	
	o Sensors, Ratemeter, Shielding;Typical Manufacturers; E.G. and G, Bendix, RCA, Baird Atomic, Nuclear Ins. GD/FW	4,500
	o Time, Altitude Signal Conditioner, Westronics, International Data System, Nuclear Ins. GD/FW.	4,000
	o Synchro Analog Repeater Signal Conditioner, Gianinni, GD/FW.	4,000
	o Miscellaneous Equipment, Consoles, Meters, Switches; International Data System, Electronic Communications Inc., Nuclear Ins., GD/FW.	5,000
4.	Ground Equipment Costs	76,000
5.	Total System Costs (55 aircraft)	21.5 Million

2.2 Alternate System

A Covey system consisting of 10 Director aircraft and 50 Survey aircraft is proposed as an alternate monitoring system for making a national survey with 50 mi. flight spacing. The Howard 500 is selected for the Director aircraft and the Beech 18S for the Survey plane. The Howard 500, although more expensive, may be more suitable for the Survey plane if factors such as crew comfort, reliability, alternate mission capability, etc., are considered.

The Howard 500 is a 35,000 pound, long range, piston type aircraft featuring a pressurized cabin and a low noise level. It is powered with two Pratt and Whitney, 2500 HP R-2800CB-17 engines. The take-off distance over a 50 foot obstacle is less than 2500 feet. Its payload and cabin space will accommodate 12-14 passengers. A cut-away drawing of the Howard 500 showing a tentative installation of equipment for a survey aircraft is shown in Figure 8.4. The cabin space of the Howard 500 is more than sufficient to permit the installation of the airborne equipment for the Director aircraft shown in Figure 8.2 for the Grumman Gulfstream.

At an altitude of 22,000 feet with the above payload, the Howard 500 has an endurance in excess of 14 hours, which is more than the endurance of the Beech 18S at low altitude. At low altitude, the range is 2177 miles at a block speed of 246 miles per hour, or 1600 miles at a block speed of 300 miles per hour.

The flight procedure for the Covey system is somewhat similar to that described above for the Flock system. The survey is made in the north-south direction. The survey aircraft will make an "up and back" survey flight sending the data as it is collected to the high altitude (20,000 ft or above) Director aircraft using UHF. The air-to-air communication between the Survey aircraft and the Director airplane is limited to line of sight. Each director aircraft will control a rectangle whose width is 250 miles on either side of its line of flight and whose length is roughly half the range of the aircraft. For a 50-mile survey interval, a covey will consist of one director aircraft and five survey aircraft. In an "up and back" flight profile, they will be spaced at 100-mile intervals.

The covey data system with digital data limiting as shown in Figure 8.7 provides automation to the data system. The survey aircraft will measure the data as in the flock system. The data output will be limited to preselected levels of radiation and will be in digital format. The data will be recorded on a digital stepping recorder which is advanced only by command of the data. At intervals, the data, along with "hot line" information, will be relayed to the director aircraft where it will be recorded on tape until it can be relayed to the Civil

Defense Regional Headquarters. From here the data will be transmitted directly to the national center where it is recorded on tape in computer format as it is received. It is assumed that the Civil Defense-Regional-to-National Communications System will be used. The computer will be used to process the data into discrete dose rate levels and to make a tape on which the data are grouped according to discrete levels. The tape will be used to drive an X-Y plotter with a Z mode to plot the data in discrete levels. The X-Y plots can be used to draw the dose rate contours and a different color of ink will be used for each contour.

3. FALLOUT FROM NUCLEAR WEAPON DETONATION

In order to devise instrumentation and monitoring techniques for aerial survey procedures it is necessary to consider some of the characteristics of the fallout patterns which might be expected from a variety of weapon explosions. A simple model which can be used to predict the effect of wind, weapon yield, altitude of burst, precipitation, etc., on the deposition of fallout on the ground is needed to analyze the requirements for a monitoring system.

Several methods of various degrees of accuracy have been developed for making estimates or predictions of the expected downwind fallout plots. Each requires a knowledge of the total and fission yields of the explosion, the burst height, and the atmospheric structure and wind patterns to the top of the radioactive cloud in the vicinity of the burst. A somewhat detailed mathematical model provides the best estimate of downwind fallout dose rates. Usually a digital computer is required to handle the great amount of input data and arrive at a forecast pattern. However, a simplified mathematical model has also been developed (Ref. 3.1) which greatly reduces the computation required. The model described in Sections 3.1 - 3.3 is an idealized-wind-fallout model and is felt to be sufficient for the purpose of determining the design parameters of an aerial survey system.

In the idealized model, use is made of a simple cloud configuration and a single "effective" wind speed, or average of the wind vectors at altitudes up to the top of the cloud. This model produces a symmetrical downwind fallout pattern. No attempt is made to indicate irregularities which will undoubtedly occur in a real fallout pattern.

In spite of the limitations of idealized fallout patterns, they are still very useful for planning purposes, as for example the problem of planning survey routes and procedures for aerial monitoring of ground fallout. Although a number of factors - such as burst conditions, weather, terrain, and weapon design - introduce uncertainties in assessing the fallout patterns, the methods to be discussed in the following section offer a valuable and convenient means for evaluating the input information required in assessing the monitoring procedures for a nuclear attack on a complex target system. They will undoubtedly underestimate the fallout in some locations and overestimate it is others.

3.1 Forecasting Technique

In general, an initial source of radioactivity is defined, describing the stabilized cloud by appropriate spatial and size distributions of radioactive particles. The "effective" wind speed or velocity pattern is determined for one or more typical conditions and the particles are tracked to the earth's surface by considering their fallout speeds and the effects of winds existing aloft. The need for quick-reference fallout patterns which can be easily used in evaluating multiple bursts and overlapping fallout conditions dictates the omission of more rigorous calculations. The methods employed in this study make use of the idealized fallout plot described above.

3.1.1 Source Model

The apparent dimensions of the initial radioactive cloud from a nuclear detonation have been documented from past weapon test measurements. Available data (Ref. 3.2) describe such parameters as mean cloud height, mean cloud radius and variability of cloud top based largely upon land surface weapon yields below the megaton range. Vertical rise of the mushroom cloud stabilizes in approximately six minutes and appears to do so independently of yield. Further expansion of the mushroom diameter for megaton devices continues for a longer period of time. The ultimate cloud diameter can be estimated from qualitative considerations and extrapolation of low yield device curves. A schematic of the source model employed in evaluating the idealized fallout patterns is shown in Figure 3.1. From qualitative statements about the activity distribution it is noted that most of the activity is present in the lower one-third of the mushroom. For megaton devices the stem radius and activity fraction is small enough to cause only a minor contribution to the downwind fallout pattern. It does,

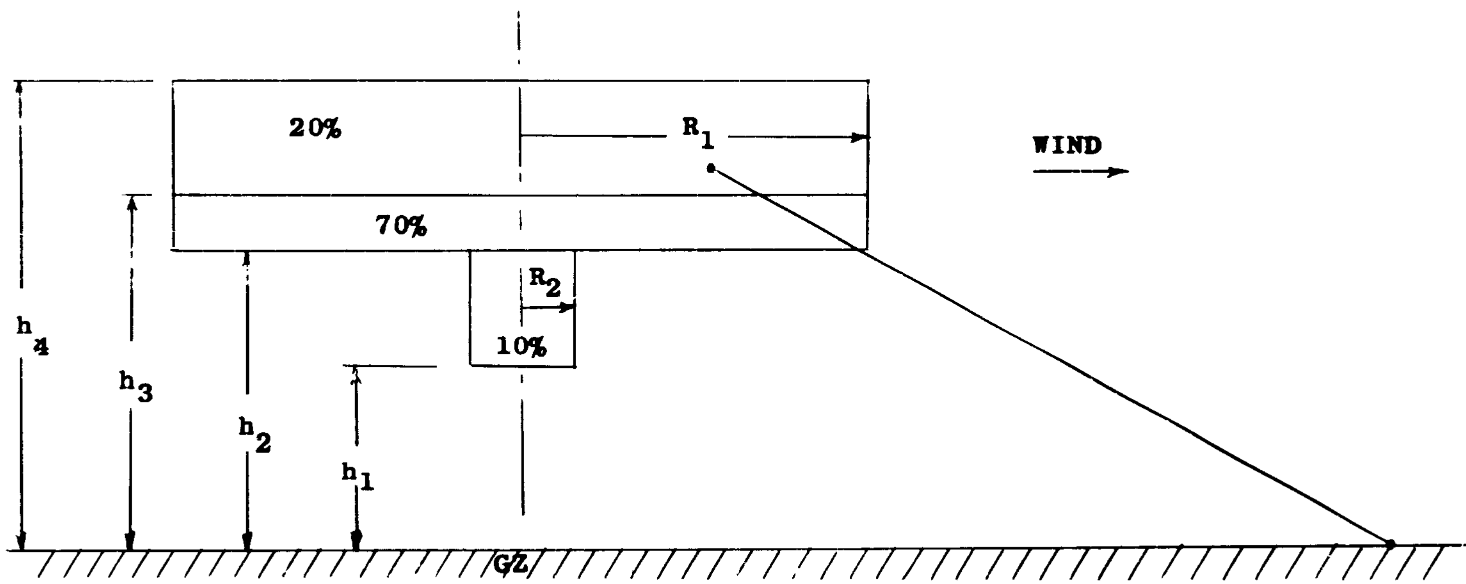

Fig. 3.1 Idealized Fallout Model

however, contribute a large amount of fallout to the ground zero area during and immediately following ascent of the cloud.

The use of "particle-size" and "fall-times" is a standard technique employed by most analytical methods. This technique simply describes a downwind plot on the earth's surface where fallout particles of certain sizes will arrive and from what altitudes they come. The initial cloud dimensions, stable cloud height, as well as particle size and activity distributions are basic data for describing the fallout pattern.

3.1.2 Particle-Activity Distribution

Significant quantities of fallout particle sizes up to 400μ will be produced in a surface burst due to entrainment of soil and earth materials. The actual distribution depends greatly upon the location of the device when it is detonated. A surface burst or underground detonation produces greater quantities of the large-sized particles while an explosion in the upper atmosphere produces only small quantities of fallout particles greater than 20μ in diameter. There is evidence that particles of this size and smaller require great lengths of time to fall from heights involved in an air burst, e.g., fallout particles of 10μ diameter (2.5 gr/cc density) fall approximately 1.5 ft/min so as to require 550 hours to fall to the ground from 50,000 feet.

In view of the large uncertainties in actual dynamics of cloud formation under the turbulent conditions of the initial cloud configurations, it is convenient to assume that all particle sizes occur at all elevations within the cloud model. The actual particle-size-activity distribution is extremely difficult to determine due to fractionation mechanisms such as fireballl condendation and concentration of fission-product activity by mass migration.

3.1.3 Time of Fall of Particles

The rate at which radioactive particles settle in the atmosphere is important, since it determines the time that the particles will spend in various wind layers. The time spent in the wind layer, combined with the horizontal wind velocity, allows calculation of the horizontal displacement of the particle. Particle fall-times to the ground from specified heights are calculated using the aerodynamic equations of motion. The effects of vertical air motions are ignored since they generally cannot be predicted and do not contribute significant lift to particles which are expected to fall in the first few hours. In the multi-layer cloud deposition analysis the particle fall-times are applied independently of the vertical wind motions unless a coherent weather forecast is available. This will introduce a certain amount of error which is larger in the downwind fallout area where dose rates are lower and will tend to overestimate the dose rates.

3.1.4 Conversion of Activity to Dose Rate

The fission yield produced by detonation of a nuclear device will be about 1.4×10^{23} BW fissions, where W is the total yield in kilotons (based on an energy release of 10^{12} calories per kiloton of TNT) and B is the ratio of fission to total yield. In deriving the scaling function for dose rate over the fallout patterns which follow, a 100% fission yield is assumed, and gross gamma activity at one hour following the burst is taken as the reference yield according to the Way-Wigner formula for fission-product decay. Because the gamma radiation is biologically more significant than the associated beta radiation (at least for the external radiation dose) the fallout activity may be stated in terms of a gamma megacurie (3.7×10^{16} photons per second).

The amount of activity present decreases with time according to a complex decay scheme for the multitude of isotopes produced. The quantitative treatment of the decay of multiple contamination from mixed fission products involves use of the relationship, $I = kt^n$ where I is the activity level or exposure rate in roentgens per unit time at time t, and k and n are empirical constants. The exposure rate is proportional to the gross activity and is a measure of the radiation produced by the source per unit time. The value of I for mixed radioactive elements may be computed for any time if observations have been made to permit determination of the constants k and n. It can be estimated to a reasonable degree of accuracy by the empirical time-decay relationship $I_{(t)}/I_o = t^{-1.2}$, where t is the time after fission.

Radiation dose rates at a sensor are also dependent upon the concentration of fallout over an area surrounding the sensor and the age of the fallout. The effective gamma energy for gross fission-product activity as a function of time after a fission burst is shown in Figure 3.2 for the range of gamma photon energies of interest. Estimates for the fallout dose rate plots are based on the dose rate obtained at a three-foot elevation. An average-value conversion factor of 7 R/hr per gamma megacurie per square mile (Ref. 3.3) provides a convenient and quite accurate basis for determination of dose rates from fallout activity during the time interval of interest (6–24 hours) in aerial surveys. This is equivalent to using the knee of the curve in Figure 3.2 as a decision point. A significant increase in the conversion factor may be expected for times less than four hours after the detonation due to the higher energy of the decay spectrum. For contamination densities differing from one megacurie per square mile, the dose rates may be scaled directly over the representative areas involved in the fallout plot. Actual dose rates near the ground will differ somewhat from the ideal case because of the roughness of local terrain and the presence of some beta activity. The corresponding dose rate reduction factor will depend on local terrain features and a variety of radiation scattering and shielding considerations. As a rough approximation, a factor of 0.7 is commonly applied (Ref. 3.5).

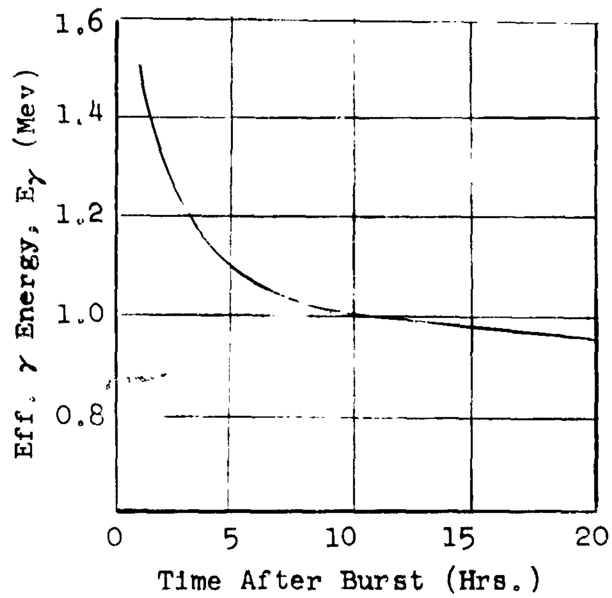

Fig. 3.2 Effective Gamma-Dose Energy Following Fission Burst - Ref. 6

Due to the relatively short mean free path of beta radiation in air, this component will not be detected by a monitoring aircraft. Consequently, the beta contribution is not considered in estimating dose rates for the fallout plots. It will, however, constitute a serious hazard for contamination of clothing and beta-burns in the case of body contamination. In this respect, the crew of an aerial monitoring system may be exposed to beta radiation while unprotected on the runway prior to take-off.

3.2 Idealized Fallout Patterns

Fallout deposition is usually considered in two general categories (early fallout and delayed fallout) depending upon the time required to fall to earth. As a rough estimate, about 60% of the total activity will settle to the earth within several hundred miles of ground zero in the first 24 hours following a large yield surface burst. The remaining activity will eventually reach the earth within three to five years as delayed fallout, most of it many hundreds or thousands of miles away.

Significant early fallout from a weapon burst will occur, in most cases, only from surface bursts where the fireball comes in contact with the ground. The contaminated area will usually be (1) a circle around ground zero where large pieces of earth, dust, and debris have been intimately mixed with fission products and other activated materials generated in the explosion, and (2) a kind of elongated pattern of contamination that will extend several hundred miles downwind from the burst. Most of the contaminated material in the ground zero circle usually descends within an hour or so and is known to result in lethal or hazardous conditions up to several miles from the center. Major emphasis is given to the downwind fallout patterns since it is here that the probability of surviving the initial blast effects is greater.

In the early stages of a surface burst, immense quantities of dirt and debris are taken up into the fireball and become radioactive. The large pieces of material fall to the earth rather quickly (in the first hour or so at the most) and form the high intensity patterns of the close-in fallout. The smaller particles return to the ground more slowly and tend to fall out over a very wide area in a direction downwind of ground zero. The extent of the contamination will depend primarily on the fission yield associated with the explosion and the prevailing meteorological conditions.

Within the fallout patterns from a single burst, the measure of fallout radiation, whether it be activity, dose rate, or maximum integrated dose, varies continuously from a minimum on the boundary of the pattern to a maximum at one or more points somewhere in the interior. The general contour of an idealized form of fallout pattern is shown in Figure 3.3. The dimensions

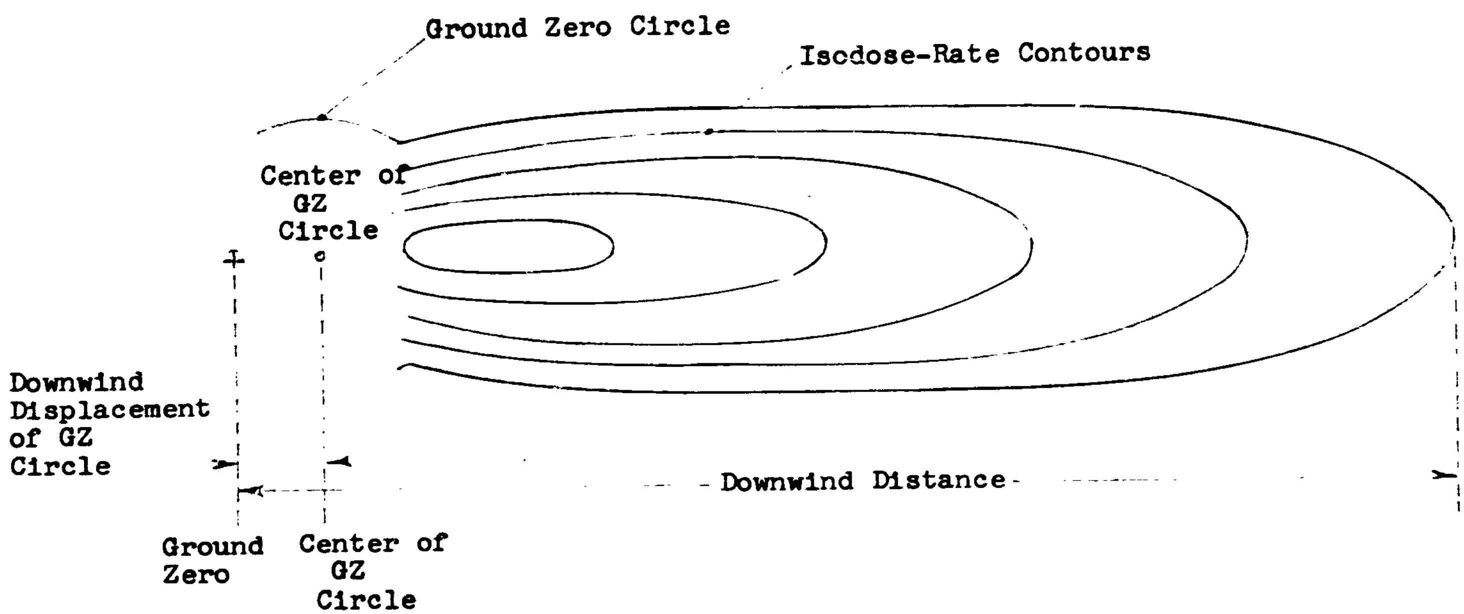

Fig. 3.3 Idealized Fallout Pattern

of the fallout pattern contours can be estimated rather crudely for various explosion yields by the "one-third power" scaling rule (Ref. 3.3). Some representative results based on the maximum dose rate contour of a 1-megaton surface burst and an ideal wind speed of 15 mph are given in Table 3.1. In this table the intensity of the fallout radiation is expressed in terms of a reference radiation dose rate 1-hour after the explosion. These data indicate quite clearly that extremely high fallout dose rates will exist over very large areas of land.

The unit-time (H+1) reference dose rate (1-hour after burst) forms a convenient basis for estimating subsequent dose rates at any time after deposition. It should be noted, however, that downwind deposition, for the most part, will not be complete for many hours after the burst. During this time, radioactive decay of the falling cloud particles will result in a decrease of intensity prior to actual deposition. For convenience, a radiation reduction factor based on the empirical decay formula (Section 3.1.4) is employed to calculate the radiation intensity at any time after an explosion. Values of the radiation reduction factor are given in Table 3.2. These, too, are rather ideal values since the empirical decay formula is based on the bulk characteristics of mixed fission product decay. Divergence from this form of decay may be expected whenever significant quantities of neutron activation products are present and/or some degree of fractionation from the mixed character of bulk fission product activity is encountered.

Table 3.1

APPROXIMATE DIMENSIONS OF CORRESPONDING MAXIMUM RADIATION CONTOURS PRODUCED BY FALLOUT, 1-HOUR REFERENCE DOSE RATE

Bomb Yield Megatons	Maximum Dose Contour R/hr	Radius of GZ Circle Miles	Downwind Displacement of GZ Circle Miles	Downwind Distance (Miles)	Crosswind Distance (Miles)
1	3000	0.43	0.60	22	3.1
2	3780	0.54	0.76	28	3.9
5	5130	0.74	1.03	38	5.3
10	6450	0.92	1.29	49	6.7
20	8160	1.17	1.63	60	8.4

Table 3.2

FALLOUT REDUCTION FACTORS

Time After Burst-Hours	Radiation Reduction Factor
1	1.0
6	0.110
12	0.049
18	0.030
24	0.022
168	0.00215
336	0.00093

Several typical fallout plots for a 1-megaton surface burst are shown in Figure 3.4. The effective wind speed is taken as 15 mph. The plots show a number of isodose rate lines for certain round number values of the dose rate as would be observed on the ground for various times after the explosion. The plots for two and three hours after the burst have been interpolated from the data presented in the "Effects of Nuclear Weapons" (Ref. 3.3) by use of the simplified cloud model described in Section 3.1.1. These plots indicate the time dependence and extent of major fallout contamination as the cloud progresses downwind. The maximum isodose contour (3000 R/hr) is the result of large particulate fallout and is seen to diminish quite rapidly. The 100 R/hr contour reaches its maximum width about one hour after the burst but continues to spread downwind as far as 22 miles in approximately two hours. In three hours the 1000 R/hr contour has receded to about seven miles. In general, the dose rate contours are seen to be related very closely to the downwind progress of the cloud until some time after six hours when cloud depletion and time-decay begins to lessen the degree of fallout activity deposited.

These results are shown more graphically in Figures 3.5 and 3.6, which indicate the fallout history for a 1-megaton burst under the effects of a 15-mph wind and a 30-mph wind, respectively. These figures indicate the downwind (centerline) progress

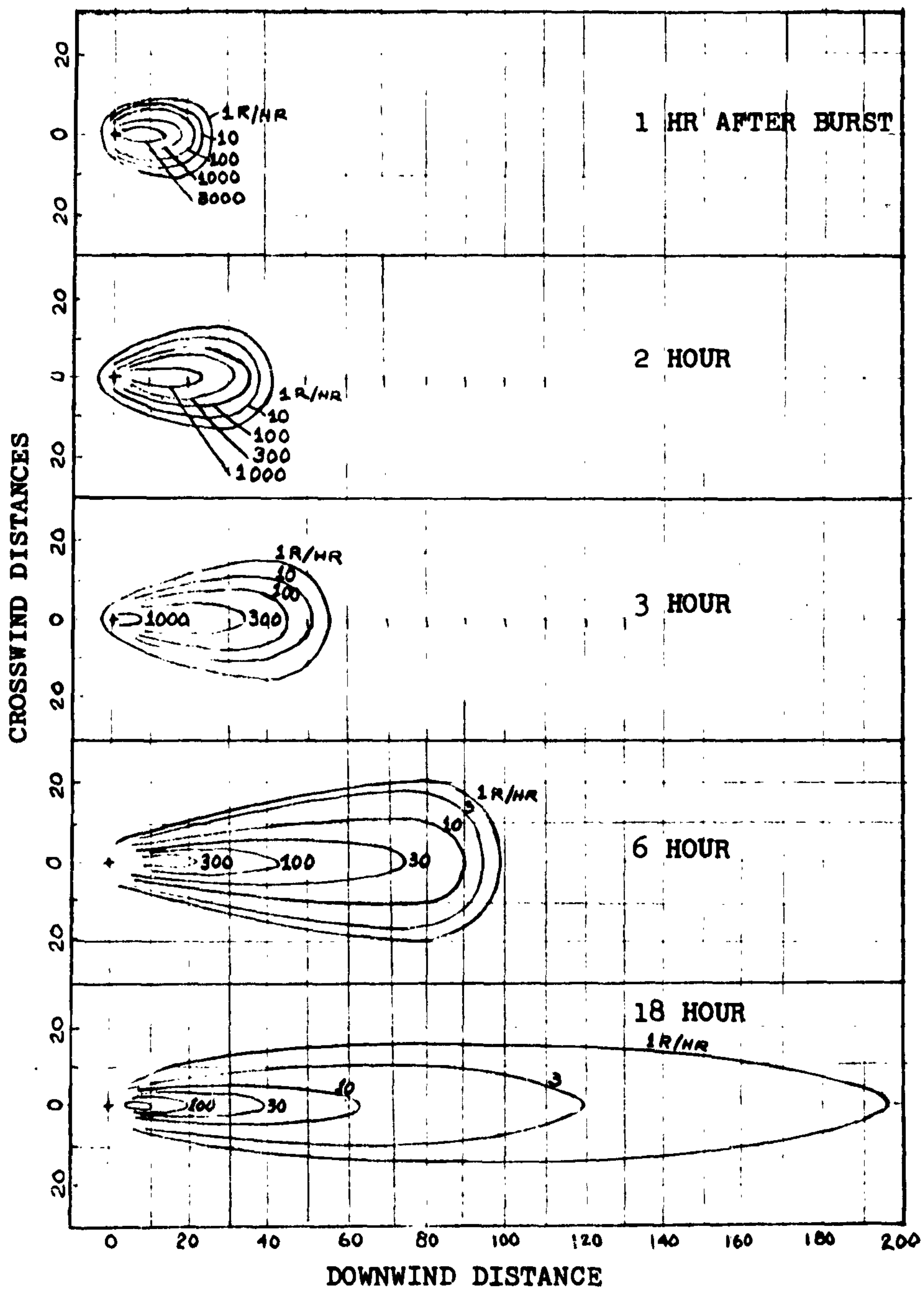

Fig. 3.4 Idealized Fallout Plots for 1 MT Surface Burst - 15 MPH Wind

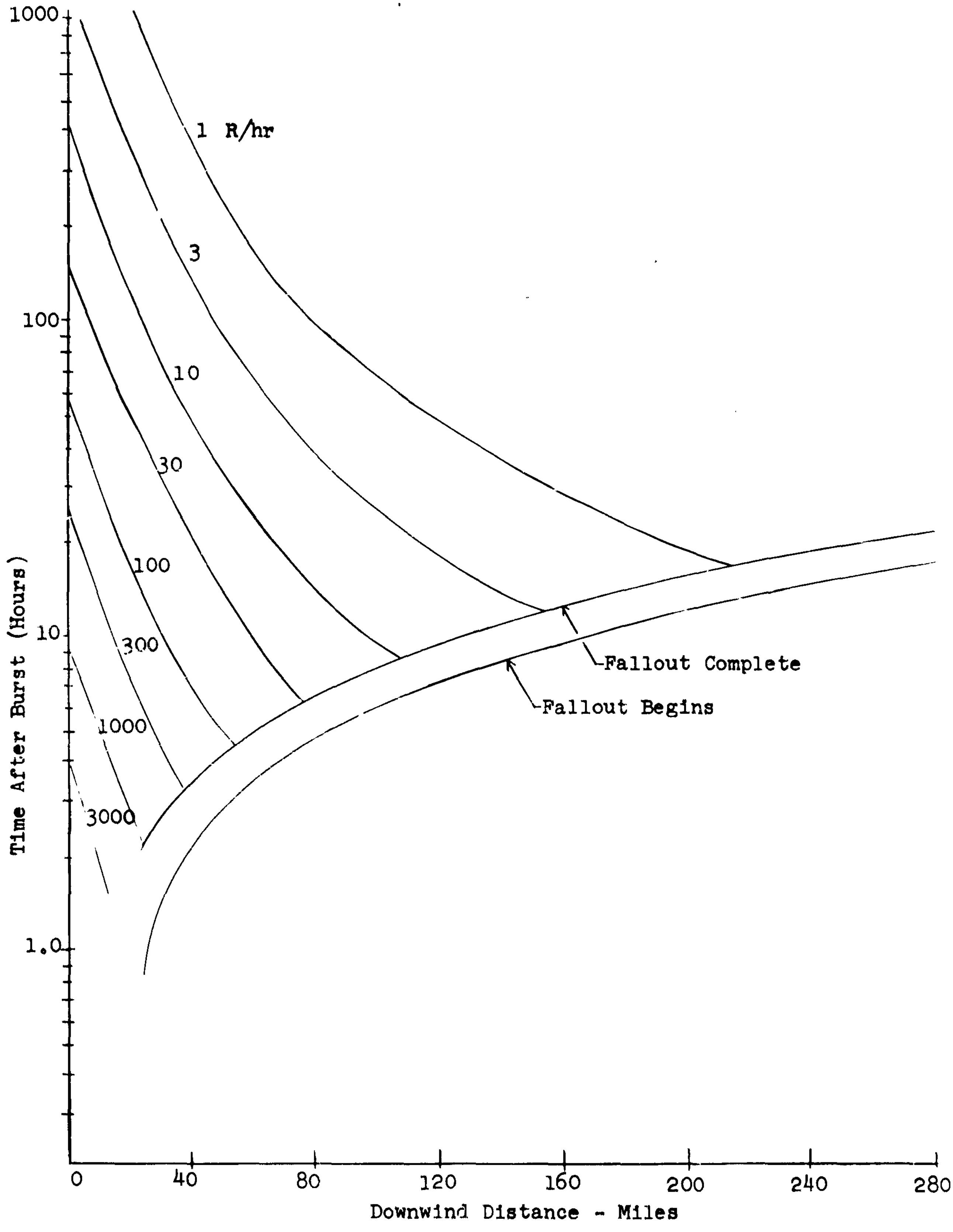

Fig. 3.5 Fallout History - 1Mt Fission - 15 mph Wind

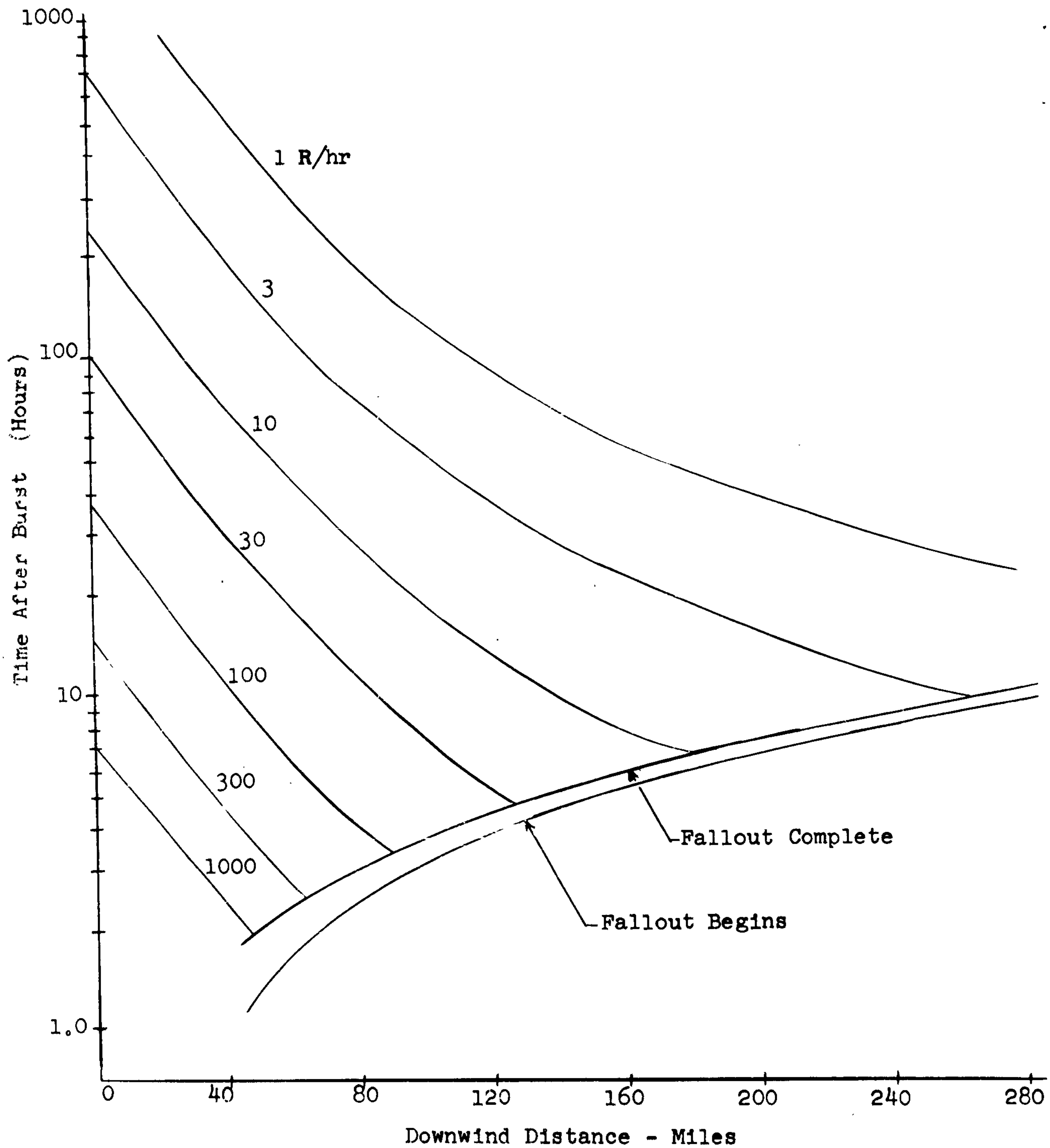

Fig. 3.6 Fallout History - 1Mt Fission - 30 mph Wind

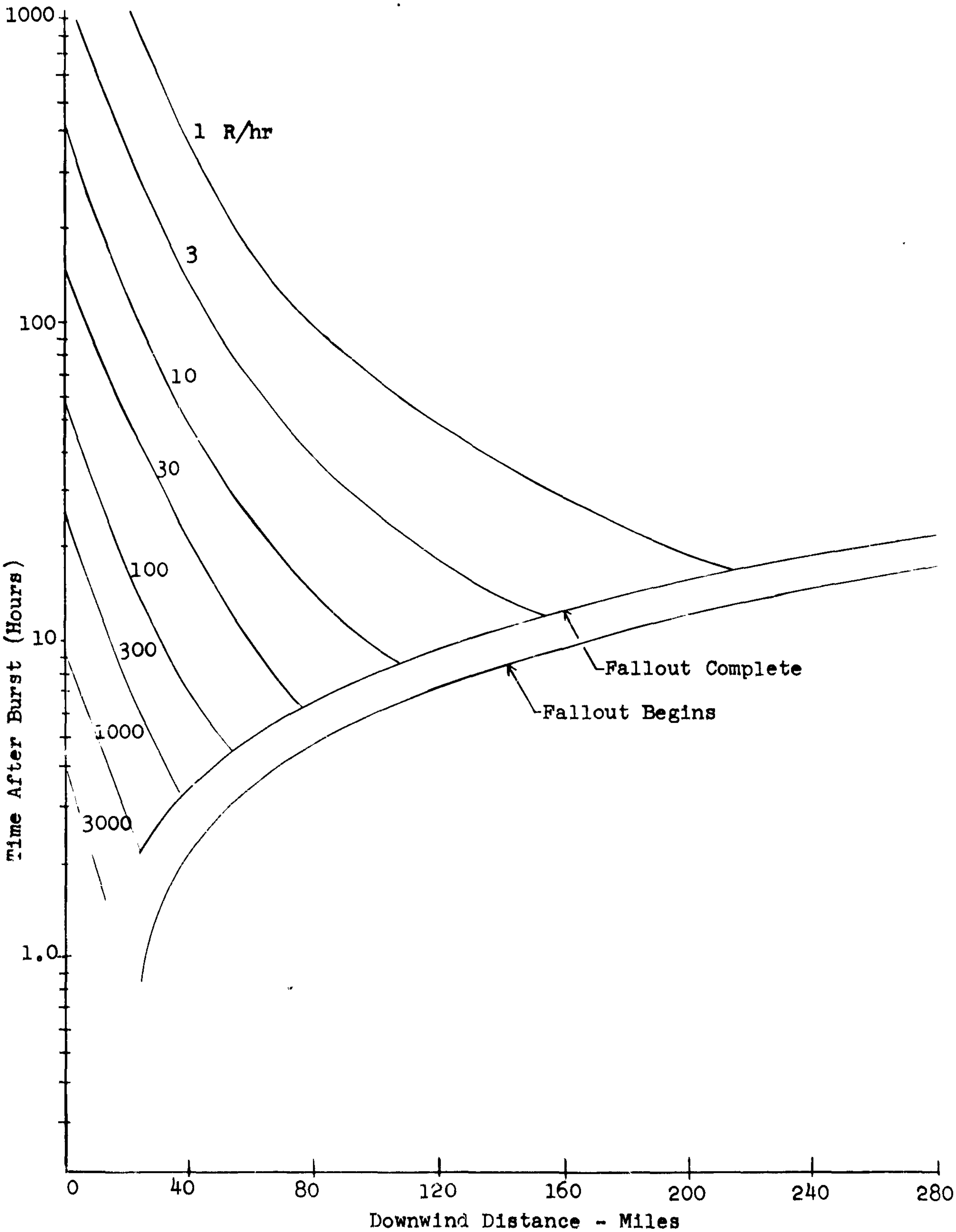

Fig. 3.5 Fallout History - 1Mt Fission - 15 mph Wind

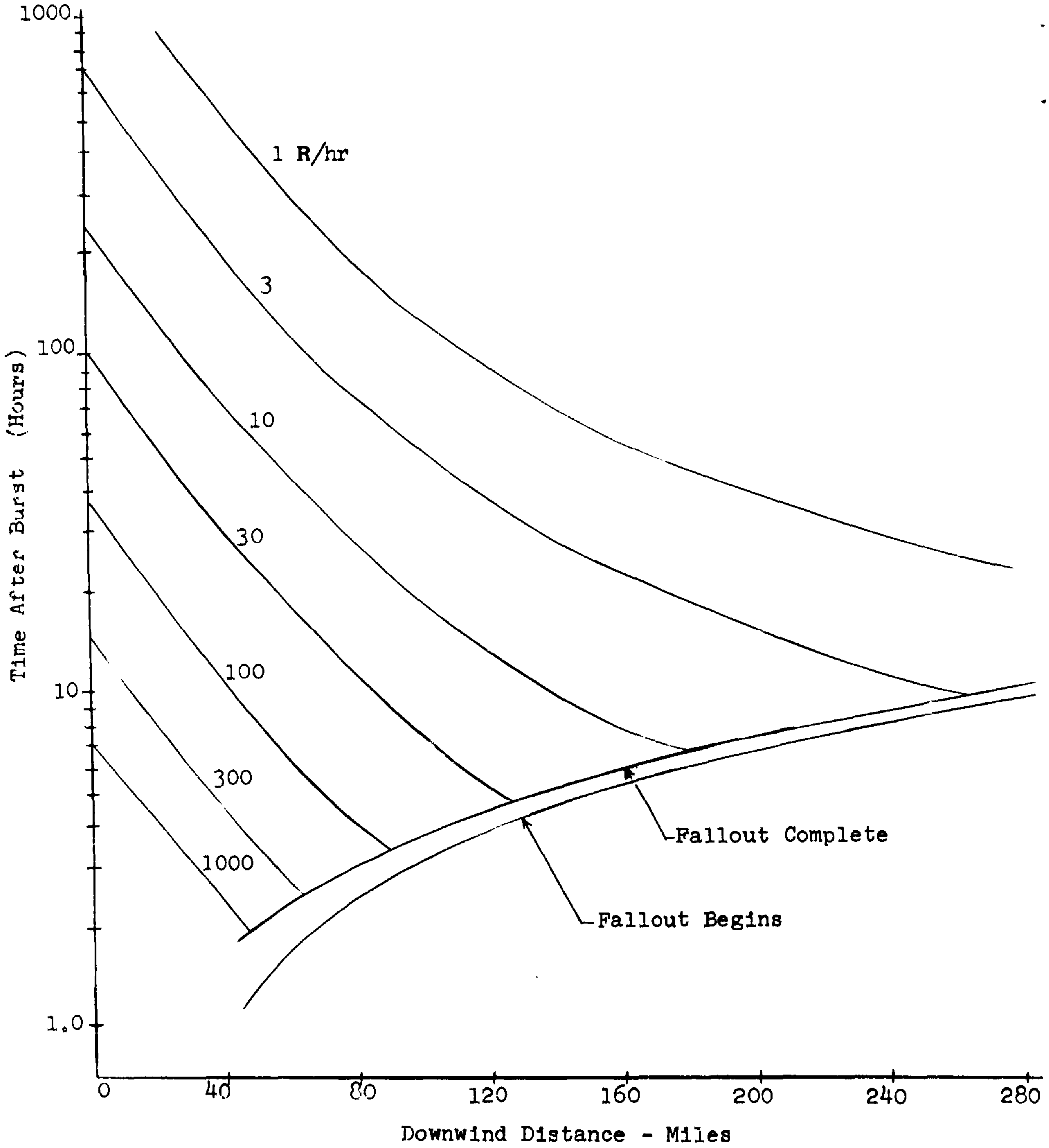

Fig. 3.6 Fallout History - 1Mt Fission - 30 mph Wind

of each of the selected dose-rate levels as a function of time after the explosion. The 1 R/hr dose rate line for a 15-mph wind reaches its maximum downrange extent somewhere around 225 miles. This occurs about 16 hours after the burst. The contour has receded to about 200 miles at 18 hours after burst. In 100 hours the contour has receded to about 80 miles downrange and continues receding with increasing time. The progress of each of the selected dose rate contours may be traced in a similar manner from the down range location at which fallout is essentially complete.

In Figure 3.6 the corresponding fallout history for a 30-mph ideal wind is shown. Under this condition the maximum downrange extent is seen to be greatly increased, the 1 R/hr contour reaching possibly to 360 miles in 16 hours. Time persistence of the dose rate levels is correspondingly lowered due to the greater dispersal of early falling particles in the downwind area.

One item that must be constantly kept in mind is that the fallout process takes time and that this time is dependent on the size of the fallout particles. If the simplifying assumptions of the early fallout patterns are accepted, then it is evident that the greatest amount of the fallout distribution is essentially complete in about 24 hours. Assuming large weapon surface bursts, significant patterns of radiation for purposes of effecting aerial monitoring surveys will probably exist on the ground as early as 10 or 12 hours. The time of cessation of fallout for any given point on the ground and the location of airborne particles from the non-depleted cloud must also be taken into consideration.

3.2.1 Effect of Wind on Fallout Patterns

To map the extensive deposition of fallout from weapon yields in the megaton range requires the inclusion of many complex meteorological variables and consideration of the fact that clouds from these large detonations extend to altitudes in excess of 60,000 feet (Ref. 3.1). The fallout plots presented in the previous section to indicate the scope of the downwind deposition pattern must be regarded as only a very rough estimate. The assumptions with regard to a one-dimensional idealized wind vector leaves much to be desired and certain of the simplifying assumptions deserve further evaluation.

The effects of varying wind speeds on the downwind fallout pattern is shown in Figure 3.7 for ideal wind speeds of 5, 15, 30, and 60 miles per hour. The radiation intensity along the centerline of the fallout pattern is given in terms of the unit-time reference dose rate as a function of downwind distance. Since, for megaton detonations, the wind speeds are much higher at the upper altitudes affecting the initial cloud configuration, it is expected that an "effective" wind speed for the more

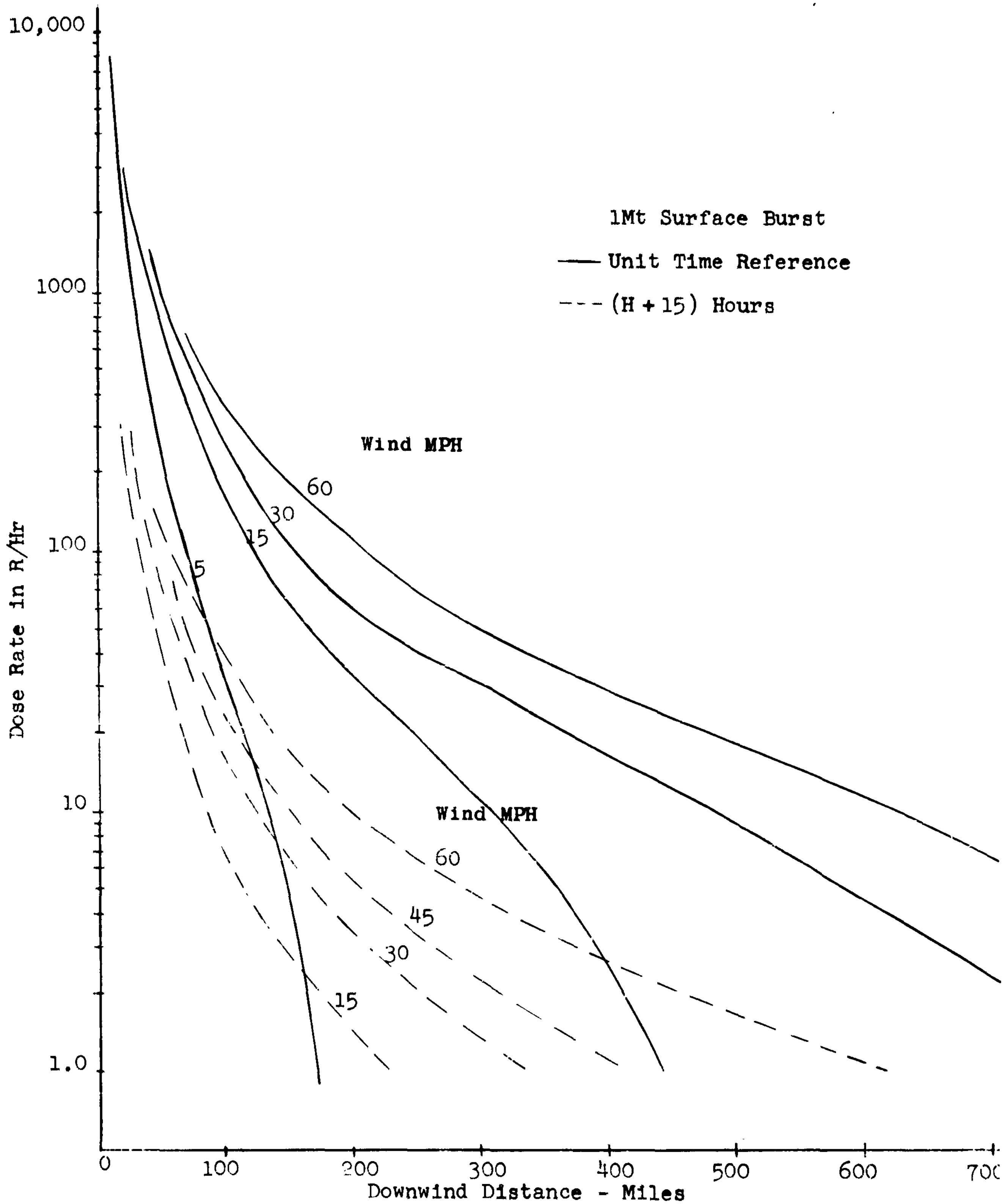

Fig. 3.7 Effect of Wind on Idealized Fallout Plots

general weather conditions may be as high as 30 miles per hour. Periodic conditions could result in persistent wind speeds as high as 60 mph and as low as 5 mph during some of the summer or winter months.

The action of horizontal wind currents is to transport particles in the atmosphere according to the direction and speed of the wind. As particles descend their motion is influenced by the winds prevailing at all levels through which the particles pass. Vertical currents existing in the atmosphere may operate to increase or decrease the rate of fall of particles as long as they are within the region of the convective activity. Turbulence does not, on the average, increase or decrease the time of fall, but because of the increased particle motion which accompanies the increased air motion, there will be an increase in the dispersion of the particles through the air with the possibility of isolated local "hot" spots.

Rains generally originate from atmospheric clouds at heights below 20,000 feet. Theoretical considerations and observations indicate that when precipitation occurs, the water drops act to scavenge the particles suspended or falling in the atmosphere. One effect of precipitation on fallout particles is to accelerate the particles already falling. Particles so small as to tend to remain suspended in the atmosphere, may adhere to precipitated water drops and consequently move downward with the drops, causing local hot spots to develop on the ground.

Magnitudes of rising air mass velocities up to 10 cm per second in dry air would support 35 micron particles and appreciably slow down larger particles. Downwind moving air masses seldom exceed 5 cm per second. The velocity of rising air masses in rain areas may be as much as 1 meter per second (Ref. 3.6), but rain would carry the particles down at velocities much greater than 1 meter per second.

Since the determination of the actual location and density of fallout activity depends on the winds encountered by the fallout particles, errors in estimating the winds will produce errors in prediction of these quantities. However, there is a limit to the accuracy of wind estimates. The standard deviation of the magnitude of this error is estimated to be approximately 10 knots for a thick layer of 50,000 feet or more (Ref. 3.7). The usual meteorological forecasts of winds compare favorably with persistence when a deep layer is involved, but the usefulness of such forecasts appears to be of doubtful value if the forecast period is extended beyond 24 hours.

Theoretical calculations to determine the distribution of early fallout usually assume that the wind blows in just one direction. In practice, however, winds at different altitudes move in different directions at different speeds. The effects of such a condition on a simplified plot of downwind fallout is shown in Figure 3.8. The situation is purely hypothetical but serves to illustrate the possible distribution due to a 10 megaton surface burst near Fort Worth, Texas, followed by a 10 megaton air burst (greater than 2-mile-burst height) over Dallas, Texas.

In preparing the fallout plot, the prevailing wind patterns for the local meteorological area were assigned. Surface winds were generally southwest at 15 mph with circulation veering gradually with altitude to northwesterly winds at 40,000 feet moving 70 mph. Stratospheric winds were westerly at about 50 mph. The effective wind speed as determined from a study of 25 wind vectors was found to be about 40 miles per hour. The two bursts are assumed to occur simultaneously and are separated by approximately 45 miles.

The 10 megaton surface burst assumed near Fort Worth is largely responsible for major downwind fallout. A cursory evaluation of the hypothetical air burst over Dallas indicates a contribution of as much as a ten percent increase over the fallout intensities expected from the 10 megaton surface burst. Downwind radiation intensities are plotted for several selected isodose contours given in terms of the one-hour reference dose rate.

The figure shows a pattern of dose-rates stretching about 400 miles downwind with a maximum width of 60 miles. The area

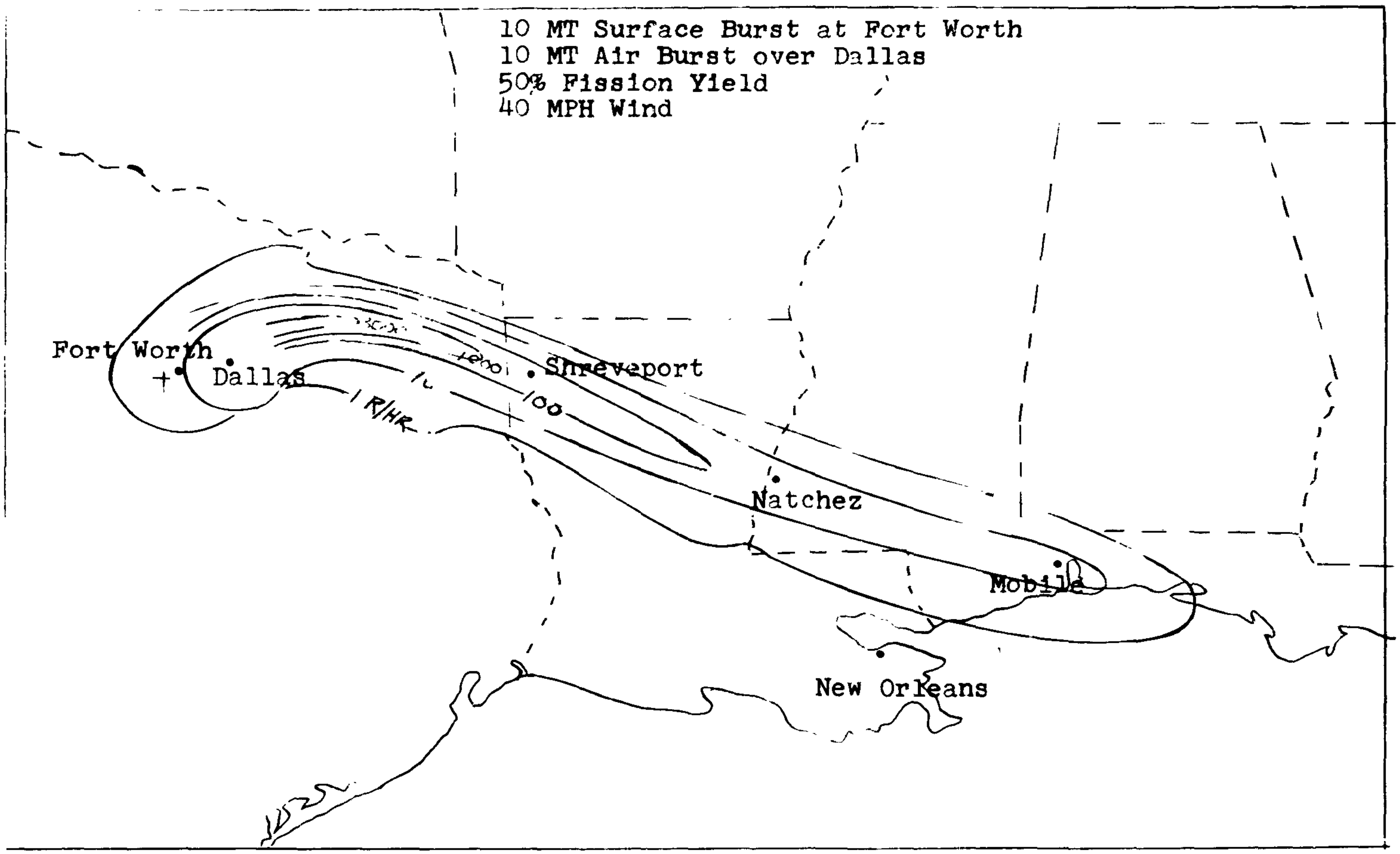

Fig. 3.8 Unit-Time Reference Dose Rate Contours

of significant deposition includes some 20,000 square miles stretching across northeast Texas and parts of Louisiana, Mississippi, and Alabama.

3.3 Time of Arrival of Fallout

In previous studies (Ref. 3.8) for low yield weapons (KT range) the time-to-peak activity has been defined as the time of arrival of fallout particles originating in the lower third of the mushroom. This has been applied for times up to 13 hours. For arrival times greater than 13 hours it is felt that the time-to-peak activity can be defined as twice the time of arrival. These relations are found to apply over a wide range of arrival times, yields, and scaled heights.

The summary analysis of the 1959 Congressional hearing on "Biological and Environmental Effects of Nuclear War" includes Table 3.3 as a summary of the principal arrival and deposition characteristics of a 5 megaton land surface burst. No indication is given of the speeds of the winds involved.

Table 3.3

ARRIVAL AND DEPOSITION CHARACTERISTIC OF A LAND SURFACE BURST

Characteristic	8-Mile Downwind	60-Mile Downwind
Time of Arrival	0.25 hr	7 hr
Time of Peak Fallout	1.5 hr	13.5 hr
Time of Peak Intensity	4 hr	10-14 hr
Time of Cessation	6 hr	16 hr

The following estimates are presented in "A Note on the Time Duration of Close-in Fallout Deposition from Megaton Explosions" (Ref. 3.1) by G. H. Gilbert. The winds chosen were those for S. W. Ontario for several days taken over intervals of three days and the cloud was divided into four layers between 10,000 and 90,000 feet. The size of the cloud was taken to correspond to an explosion of about 5 MT yield. The average wind speeds given in Table 3.4 are averaged over the 40,000, 60,000, and 80,000 feet "effective" wind values; seasonal values of S. W. Ontario are 30 mph in summer and 60 mph in winter. The peak dose rate occurs before the end of the deposition period since the decay rate exceeeds the increase in dose rate from continued deposition (see also Figs. 3.5 and 3.6).

3.4 Variations From Idealized Fallout Patterns

The technique for predicting the fallout patterns which have been presented in the preceding pages are applied only as a rough tool to delineate the possible extent and magnitude of areas containing dose rates above 1 R/hr. It is unlikely that much would be gained by applying refinements necessary for a complete and rigorous solution of each problem; the natural limitations to prediction of meteorological conditions at some unknown time corresponding to a nuclear attack, precludes the possibility of prevenient fallout estimates. With more adequate data on the size and activity distribution of particles,

Table 3.4

TIME-DEPOSITION CHARACTERISTICS OF FALLOUT

Downwind Distance	50 miles		100 miles		150 miles	
Avg. Wing Speed	(a)	(b)	(a)	(b)	(a)	(b)
			Summer			
15	1.8–7.8	3.7	4.8–14	9.2	7.7–20	13
30	0.9–2.9	2.0	2.3–4.5	3.7	3.7–6.5	5.3
			Winter			
40	0.8–2.7	1.5	1.8–3.5	2.5	2.9–4.8	4.3
65	0.5–1.5	1.2	1.0–2.3	1.8	1.7–3.3	2.5
80	0.4–1.3	0.8	1.0–1.7	1.5	1.5–2.3	2.1

(a) – Duration of Deposition in hours.

(b) – Time of Peak Intensity in hours.

latent analyses of the fallout deposition may be accomplished but determination of the actual fallout patterns will ultimately depend upon some form of monitoring survey.

In addition to the foregoing analysis of idealized fallout patterns, another calculation was performed for a 5 megaton surface burst using the average wind data of Washington, D.C., for March 1962, together with the simplified mathematical model developed by R. R. Rapp of Rand Corporation (Ref. 3.1). The results of this evaluation indicated changes in the form of the dose rate contours as in Figure 3.9.

Due to the persistence of higher wind velocities in the upper atmosphere, the long downwind patterns are still found to prevail but differences in the speeds and directions of the winds of the lower atmosphere result in a non-symmetrical cross-wind pattern. This is shown graphically in the fallout plot of the Smokey Event from Operation Plumbbob (Fig. 3.10). The local irregularities and separated regions of high activity are characteristic of downwind deposition under actual conditions.

In the event of particularly calm weather conditions where the direction of the winds change with altitude and the velocity of the wind is small, it is conceivable that fallout patterns for even the high yield devices might result in considerable close-in deposition as shown in Figure 3.11.

Winds – Miami 1200 Gmt. October 30, 1961

Infinite Plan Reference Dose Rates at (H + 1)

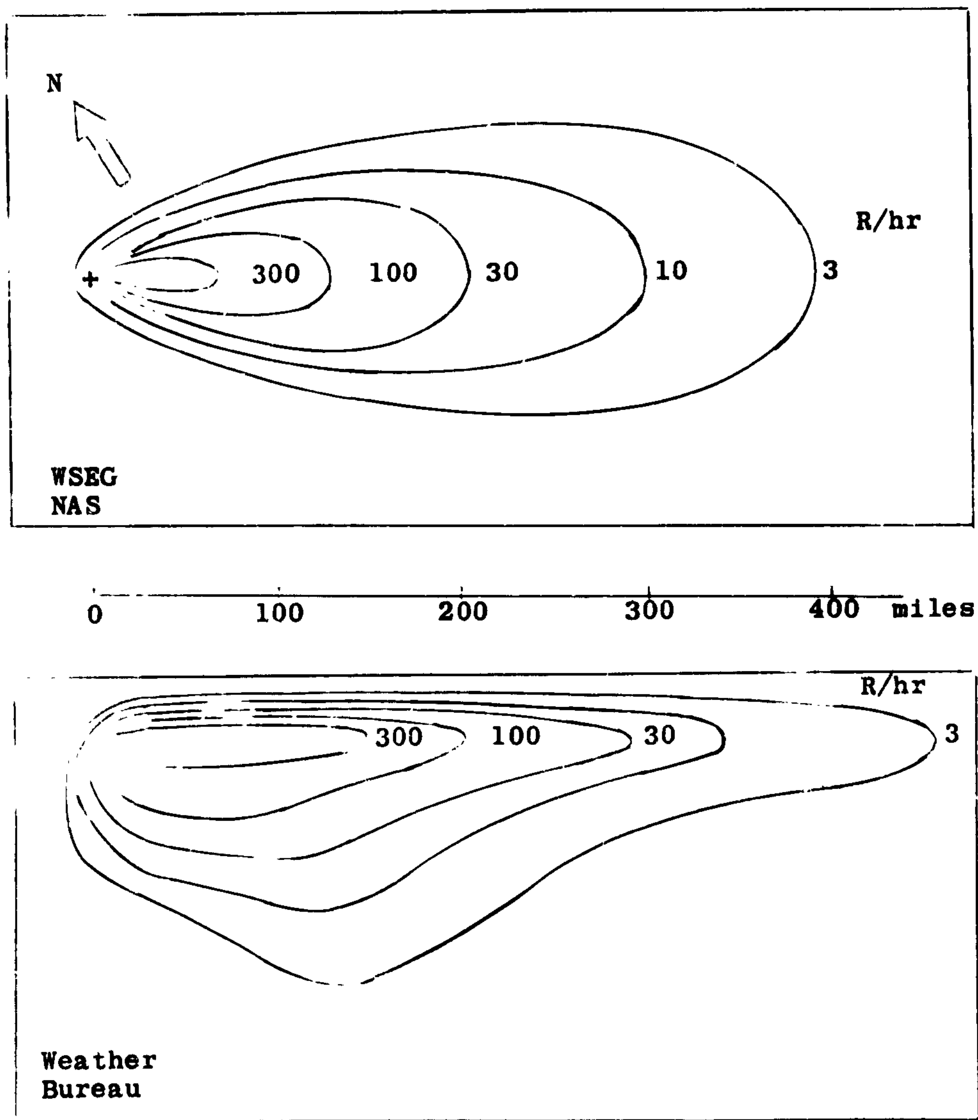

Fig. 3.9 Comparison of Idealized Patterns and Detailed Computation – 1 Mt

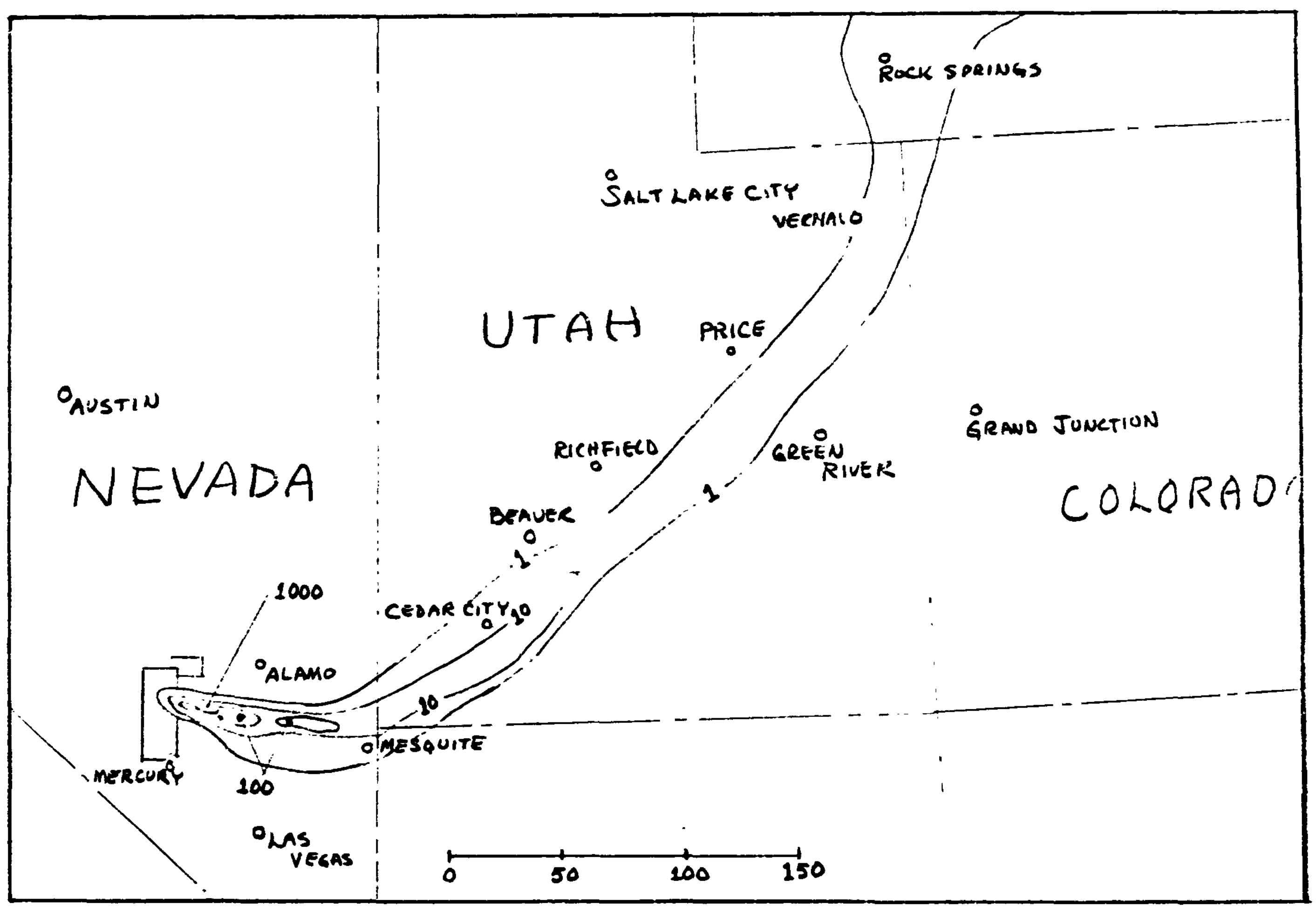

Fig. 3.10 Smokey Event (Operation Plumbob) Fallout Pattern

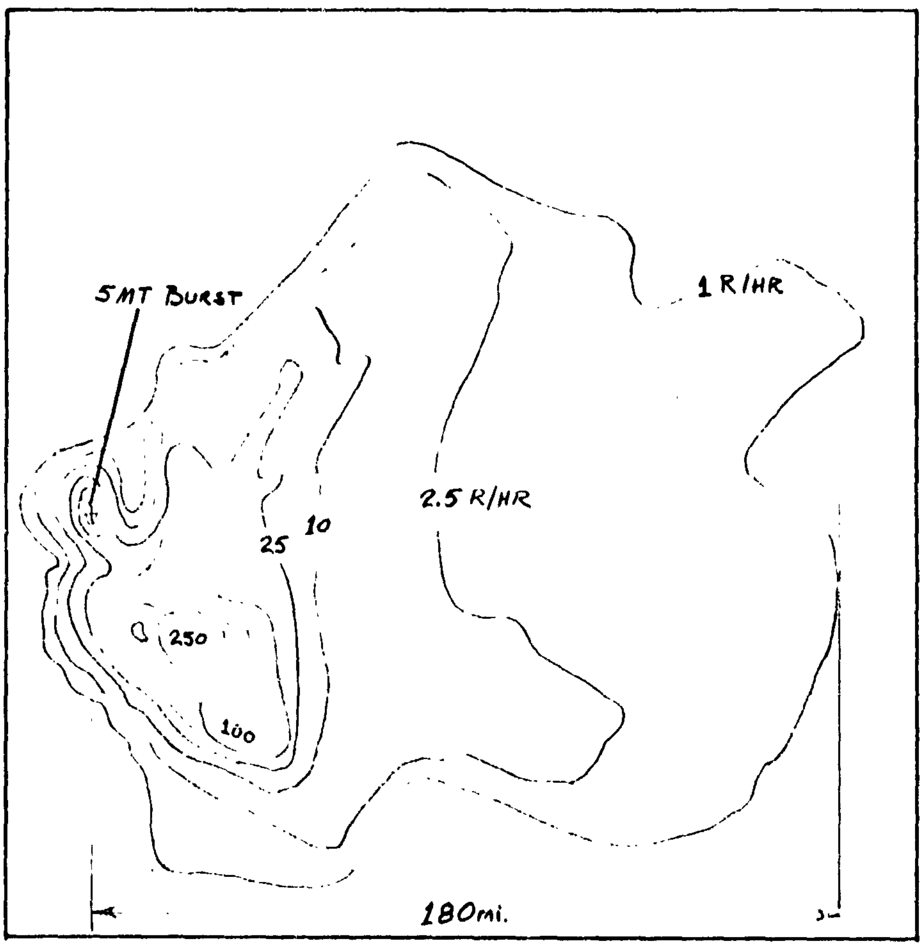

Fig. 3.11 Nonidealized Fallout Pattern

3.5 Idealized Fallout Pattern From Multiple Bursts

It is expected that much of the country will be exposed to fallout from more than one burst. From the standpoint of collecting, processing and reporting dose rate readings, the consequent overlapping of fallout which results from multiple nuclear weapons bursting at different locations and at different times must be considered. The likelihood that fallout from more than one weapon may occur at a given location may be predicted to some extent if knowledge of the target system, meteorology, and enemy strategy is assumed; but any prediction of the time of burst would be most uncertain.

3.5.1 Effect of Separation of Burst Points

The first type of fallout pattern to be examined is caused by the simultaneous (defined as within a half-hour or so) explosion of several weapons in close proximity. This might occur when two or more separate targets are located close together, or when target characteristics would require scheduling several weapons for high destruction probability. Figures 3.12 and 3.13 illustrate the idealized patterns obtained from two overlapping bursts and include a reference burst for comparison. All bursts shown are 1 MT with a 15 mph effective wind velocity. For cross-wind separation distances of five miles or less (which might be obtained by multiple bursts against a single target), the resultant patterns are similar to the single burst pattern, except

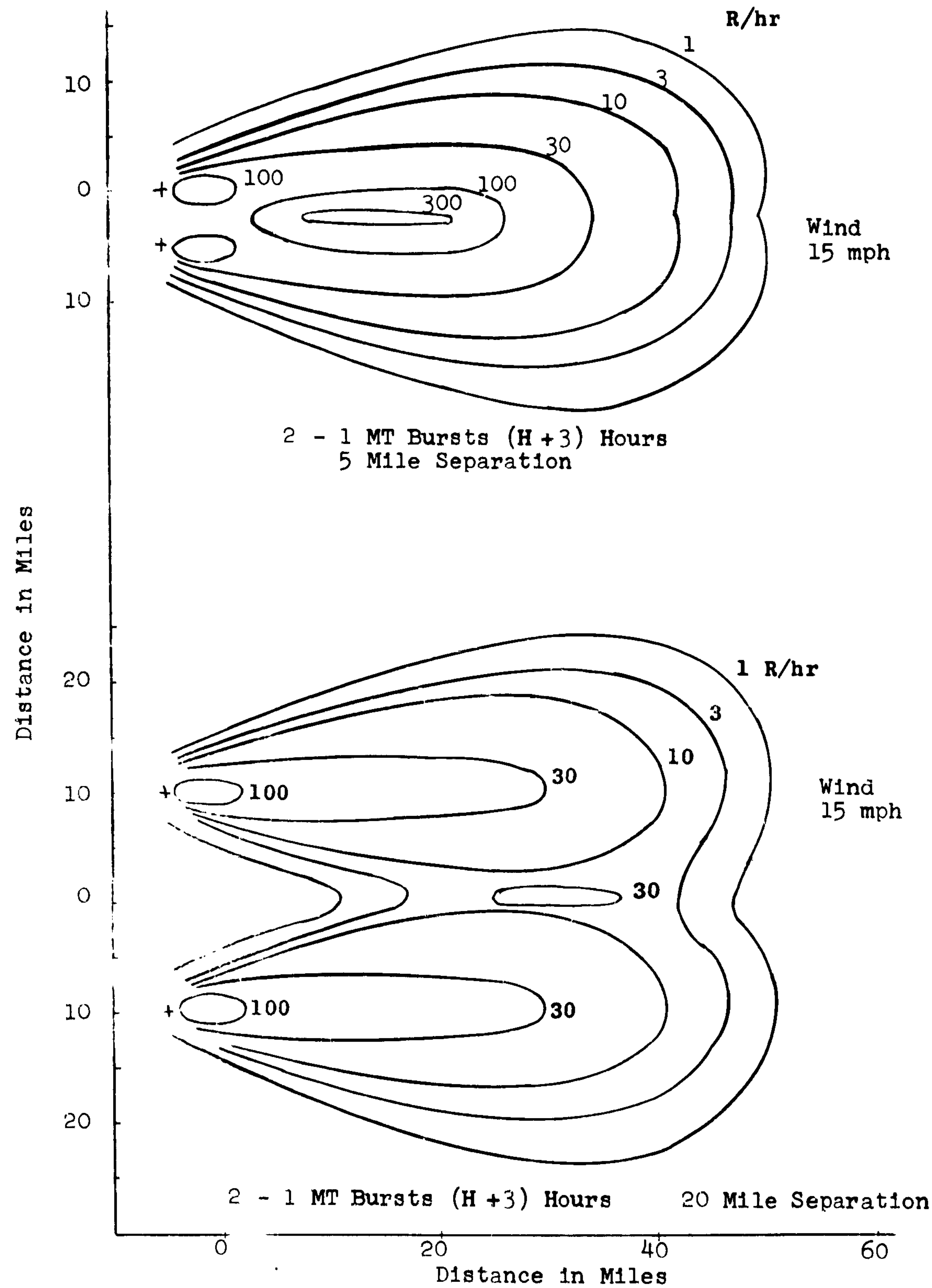

Fig. 3.12 Fallout Overlap at (H + 3) Hours

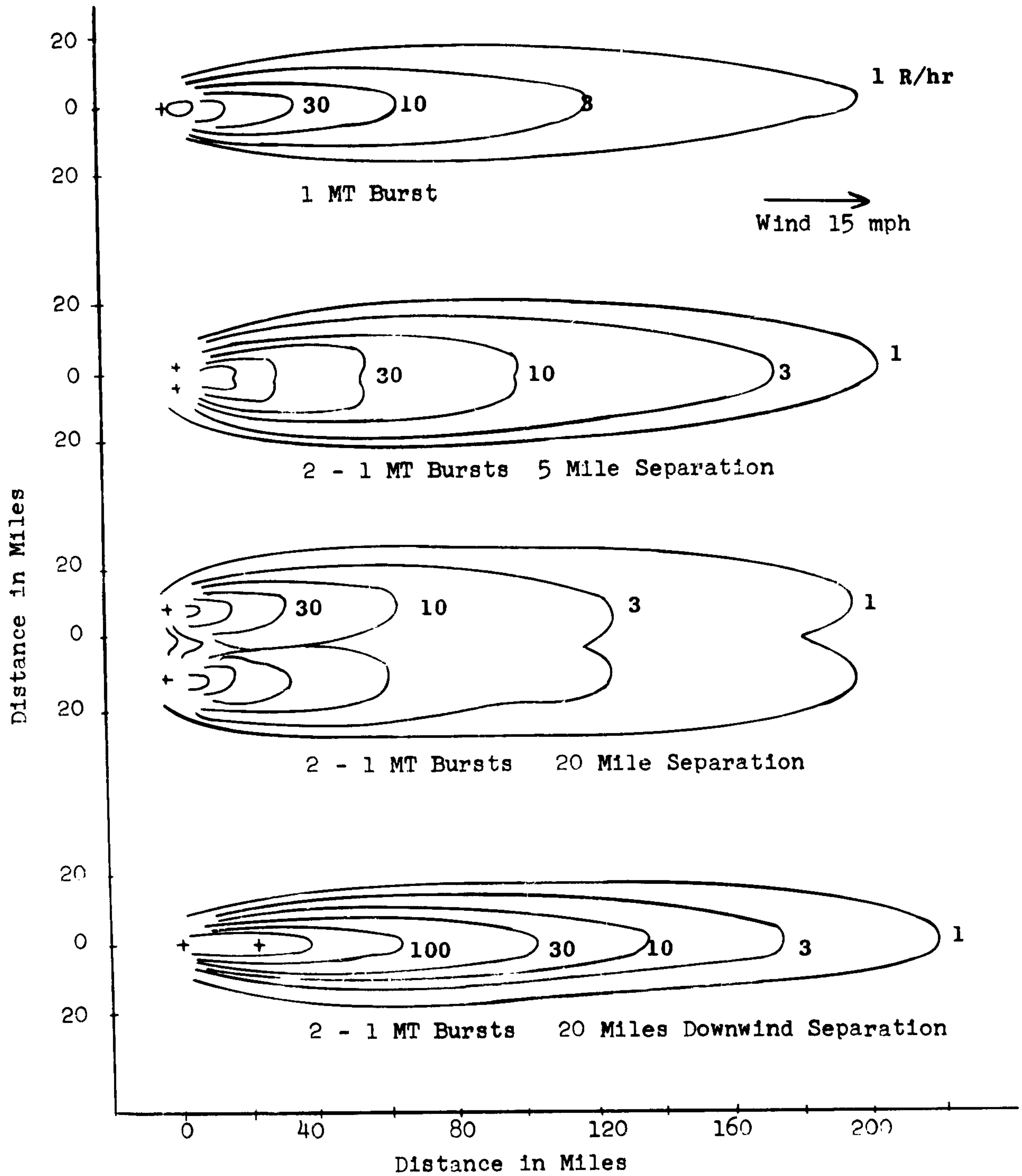

Fig. 3.13 Fallout Overlap at (H +18) Hours

for the increased width and somewhat greater downwind distance of the higher dose rates. For crosswind separations of five to 15 miles, the low isorates are similar to those of a single burst, except for the increased width; but the higher dose rates begin to form in separate hot spots downwind of each of the burst points. However, the area of lesser activity between the hot spots is very small, and might be eliminated if shear winds were present.

For separations greater than 15 miles, the isolines indicating an appreciable level of activity are completely separated; but as before, the separation is small and shear winds might eliminate the low dose rate areas. For downwind separations, the lengths of the isolines are increased, but no other changes are noticeable.

The tendency for the isolines to separate (crosswind bursts) into hot spots downwind from each burst point increases with the age of the pattern, and progresses from the higher activity levels down to the lower levels, even when shear winds are present.

Because of the uniformity and persistence of the wind flow at the high altitudes of the cloud, and the relatively small effects of shear winds, it is unlikely that the axes of simultaneous bursts will cross, and thus, only parallel hot lines are considered.

The (crosswind) separation distance at which the bursts can b^ considered as separate depends on both the plotting accuracy of the monitoring system and the significance to the user of the narrow, low-activity area between the hot spots. At time (t + 15) hours or later the minimum separation may thus vary upwards from 20 miles to as much as 60 miles for 1 MT bursts.

The (downwind) distance between bursts necessary for them to be considered as separate bursts is at least as great as the length of the highest isoline of interest at the time the survey is being made. The overlap will extend farther, but it should not be difficult to determine that there are two sources and two distinct patterns.

The additive effect of multiple simultaneous bursts separated 100 and 300 miles in the downwind direction is shown in Figure 3.14. The dose rate contribution from burst 1 does not appreciably extend the length of the dose rate contours for burst 2. The same remark holds for burst 3. Thus, with a random pass through the area the probability of intercepting a 300 dose rate line from burst 1 is essentially the same as that for burst 2 or burst 3. Hot spots (closed contours) can be expected for the 100 and 300 R/hrdose rates between each of the three bursts. The 30 R/hr and 10 R/hr rates will form closed contours between bursts 2 and 3, but will not between bursts 1 and 2. It is emphasized that the preceding remarks apply to idealized fallout

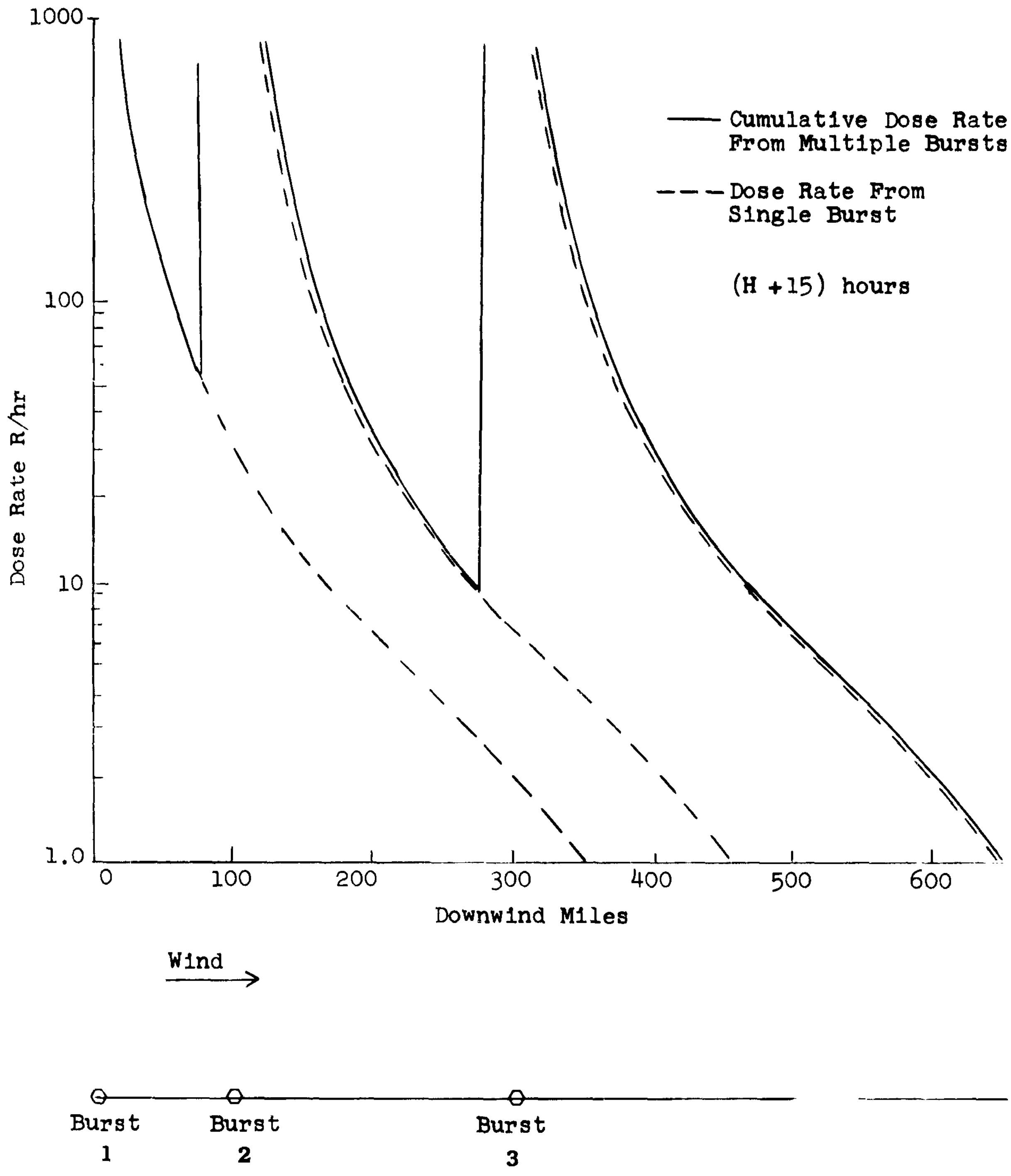

Fig. 3.14 Additive Effect of Multiple Simultaneous Bursts

patterns and some variation can be expected where shear winds are present. Again, the separation distance required depends on the downwind separation of monitoring points and the importance of the area between the two high-rate areas. Minimum separation distances are shown in Figures 3.15 and 3.16.

3.5.2 Effect of Time Separation of Bursts

The second major category of fallout pattern is caused by multiple bursts occurring at different times, either at the same spot or at different locations. In addition to the problem of determining the dose rate contours resulting from the overlapping patterns, this category has the problem of prediction of dose rates at a later time since the fallout at any point is a mixture of radiation activity of different ages with different decay rates.

The dose rate at any time after a 1 MT bursts is shown in Figures 3.5 and 3.6 for several locations downwind from the burst point. If fallout from another burst occurred at one of these points at some later time, it is apparent, from an inspection of the slope of the curve at appropriate times, that the fallout from each bomb decays at different rates. Thus, if only the total rate is measured, and either the first or second burst is used as a reference time, an error will occur when an estimate of activity is made for a later time.

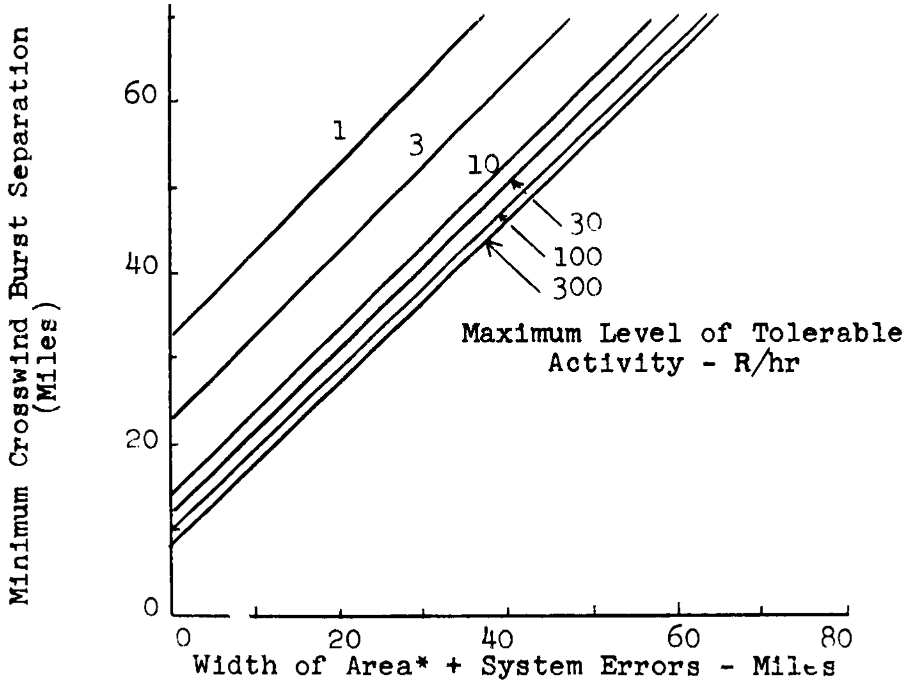

Fig. 3.15 Separation of Multiple Bursts - Effect on Width

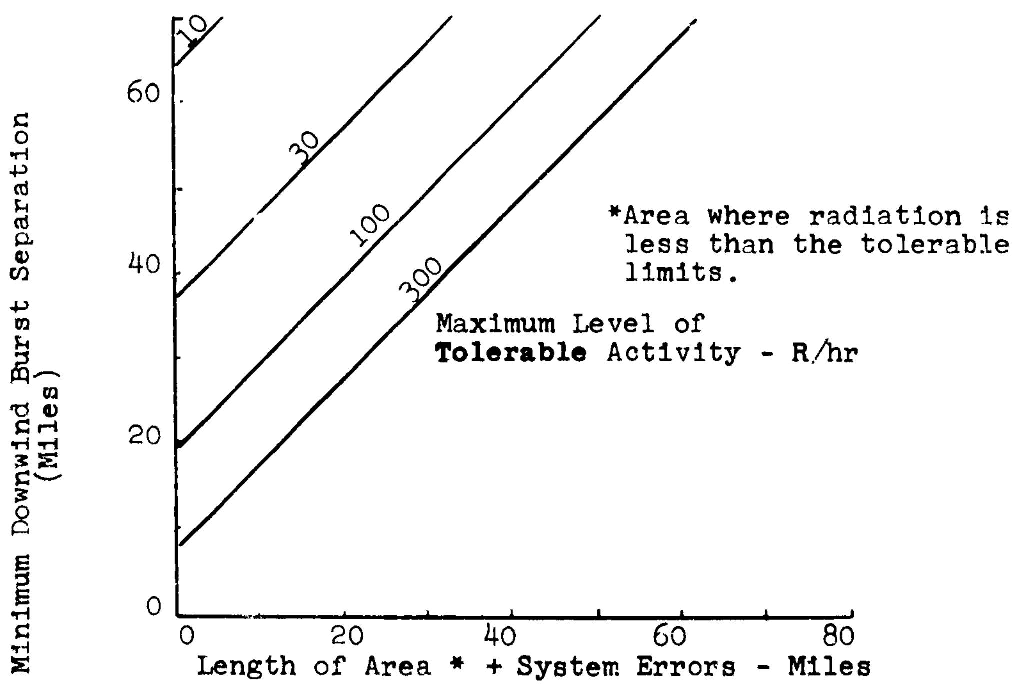

Fig. 3.16 Separation of Multiple Bursts - Effect on Length

A mathematical treatment of time scaling to account for decay of fallout radiation is given in Section 10.4 of this report. A quantitative relationship is given for dose rate as a function of time after burst for fallout from simultaneous bursts. Several approximations to account for the decay of a mixture of residual radiations of different ages are computed and boundary conditions for estimating the error are given.

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4. DISTRIBUTION OF EXPECTED FALLOUT AREAS

To assist in defining requirements for an aerial monitoring system, an assumed target system and the related distribution of fallout areas are described in this section. The location of civilian airports suitable for basing survey aircraft is considered from the standpoint of survival from blast and heat as well as from the effects of fallout.

4.1 Target Distribution

The target system shown in Figure 4.1 was chosen to represent a maximum enemy effort against both military and non-miliary strategic targets. Approximately 125 military installations and cities (communication and supply centers) were located throughout the United States. The distribution of these targets is heavy in the northeast, south, and southeast with clusters on the west coast. Only scattered targets are shown throughout most of the remainder of the country. This target system is not intended to include all possible targets, although the representation of the distribution of the targets is believed to be reasonable for various enemy strategies. However, no accuracy in analysis is lost because of the omission of targets.

The fallout pattern, not the burst point, is of primary concern for the monitoring system. For large bursts the pattern will approximate a rectangle of 80 by 500 miles. Thus, it is

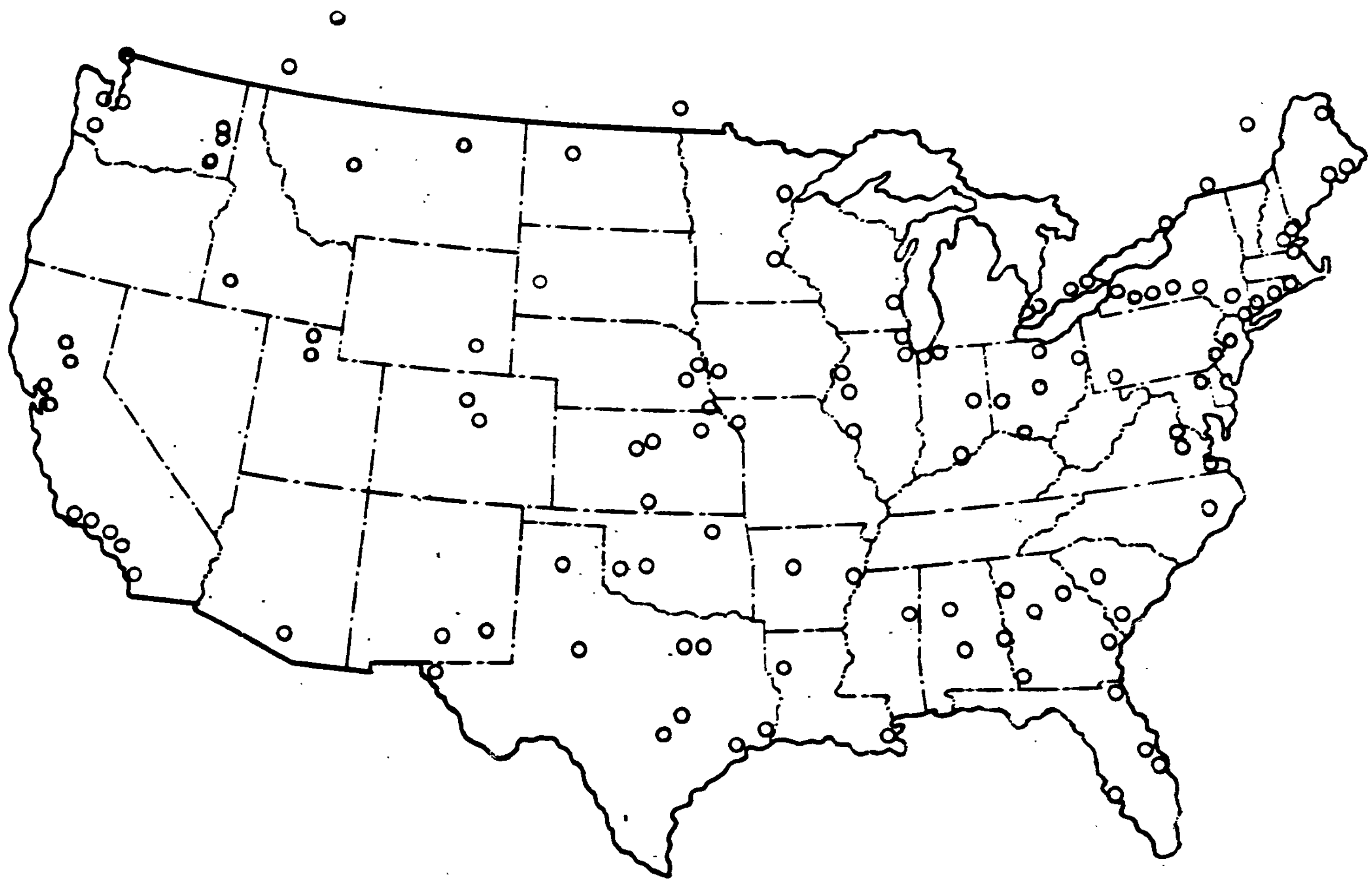


Fig. 4.1 An Assumed Target System

apparent that only a few bursts may cover an entire area with fallout, and additional bursts (from omitted targets) would only increase the fallout level without adding appreciably to the size of the fallout area, so that no additional monitoring is required. This condition prevails in the eastern section of the country and to some extent in the southern part.

In the west, there is only a limited number of targets so that large areas free from fallout can be expected. Even so, the monitoring system must be designed to survey areas where no bursts are expected in order to locate fallout from erratic bursts which may occur. However, a search procedure to determine the presence of a fallout area does not require the fine detail that would be used to monitor a fallout area.

4.2 Fallout Distribution

The distribution and extent of fallout over the United States which can result from one or more burst points in the neighborhood of each target of the assumed maximum target system is shown in Figure 4.2. The map was constructed using a wind pattern typical for a midsummer day at (H+15) hours. It is assumed that the general direction and extent of the fallout area would be determined by winds at high altitude. Low altitude and surface winds will tend to smear these patterns, making them broader, possibly shorter, and somewhat irregular along the edges.

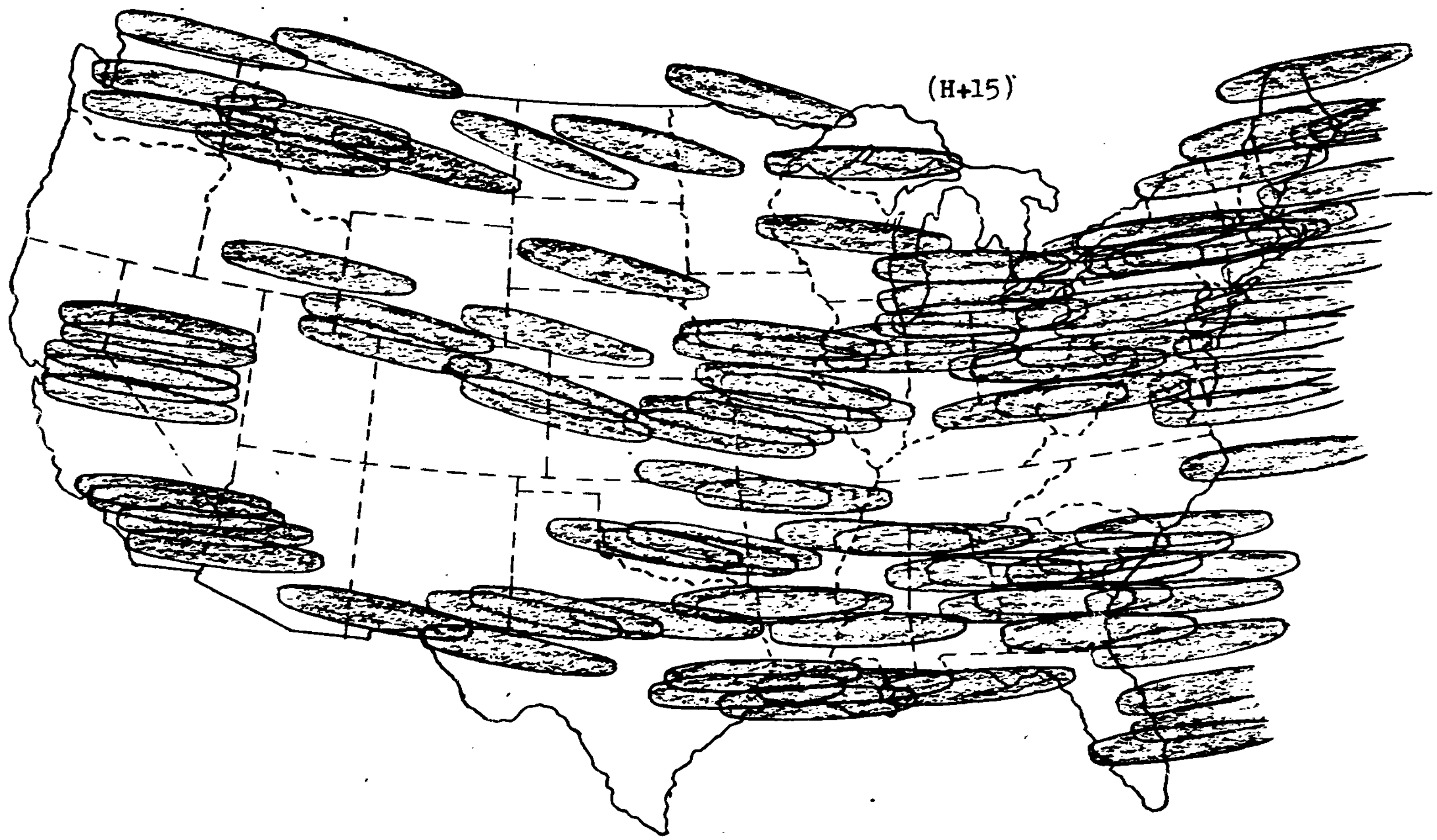


Fig.4.2 Example of Fallout Distribution

The explosions are assumed to have fission yields ranging from one to five megatons, with most of the smaller being delivered by ICMB's. The amount of fallout increases with fission yield which may increase the width of the fallout area but has little effect upon the length. Using 1 R/hr dose rate as a boundary, the maximum distance across a fallout area varies from 50 miles for a 1 MT to 80 miles for a 5 MT burst. The length may vary from 80 to N miles, depending upon wind speed.

From 4 to 8 bombs can be expected at each hardened military installation and from 1 to 4 at large unhardened area targets, depending upon the magnitude of the strike and the weapon delivery system used. With present estimates of delivery accuracy, bursts will be clustered around aimpoints. Thus, it is assumed that multiple warheads aimed at a single target would form a single fallout pattern. However, fallout of different ages may be present since it is unlikely that multiple weapons would be scheduled to arrive simultaneously at a given target.

There may be bursts at points far removed from any possible target. These would be caused by gross guidance and navigation errors or by our defensive measures (Dead Man Drops). No prediction can be made concerning the location or number of these erratic bursts.

The possible variations in the distribution of fallout over the United States caused by seasonal variations in high altitude wind direction is shown in Figure 4.3. The direction of the hot line will vary more than 45° on either side of the east-west direction only a small percent of the time, and these variations will occur mainly over small areas. Thus, a north-south movement of the survey aircraft would, in general, cut the downwind hot line, and consequently, the dose rate contours, within 45° of the perpendicular. This leads to the decision to design the monitoring system to make survey flights in the north-south direction. For areas where the predicted wind at the time of the survey varies more than 45° from east-west, individual aircraft can alter their flight paths to cover the area to which they are assigned.

4.3 Base Survival

The monitoring system must survive the initial enemy attack since it will not begin operating for some time after the first burst falls. This means survival from nuclear effects including radiation from fallout as well as from the effects of blast and thermal radiation. Thus, all facilities associated with the aerial monitoring system must be favorably located with respect to the target system. In addition, adequate facilities must be

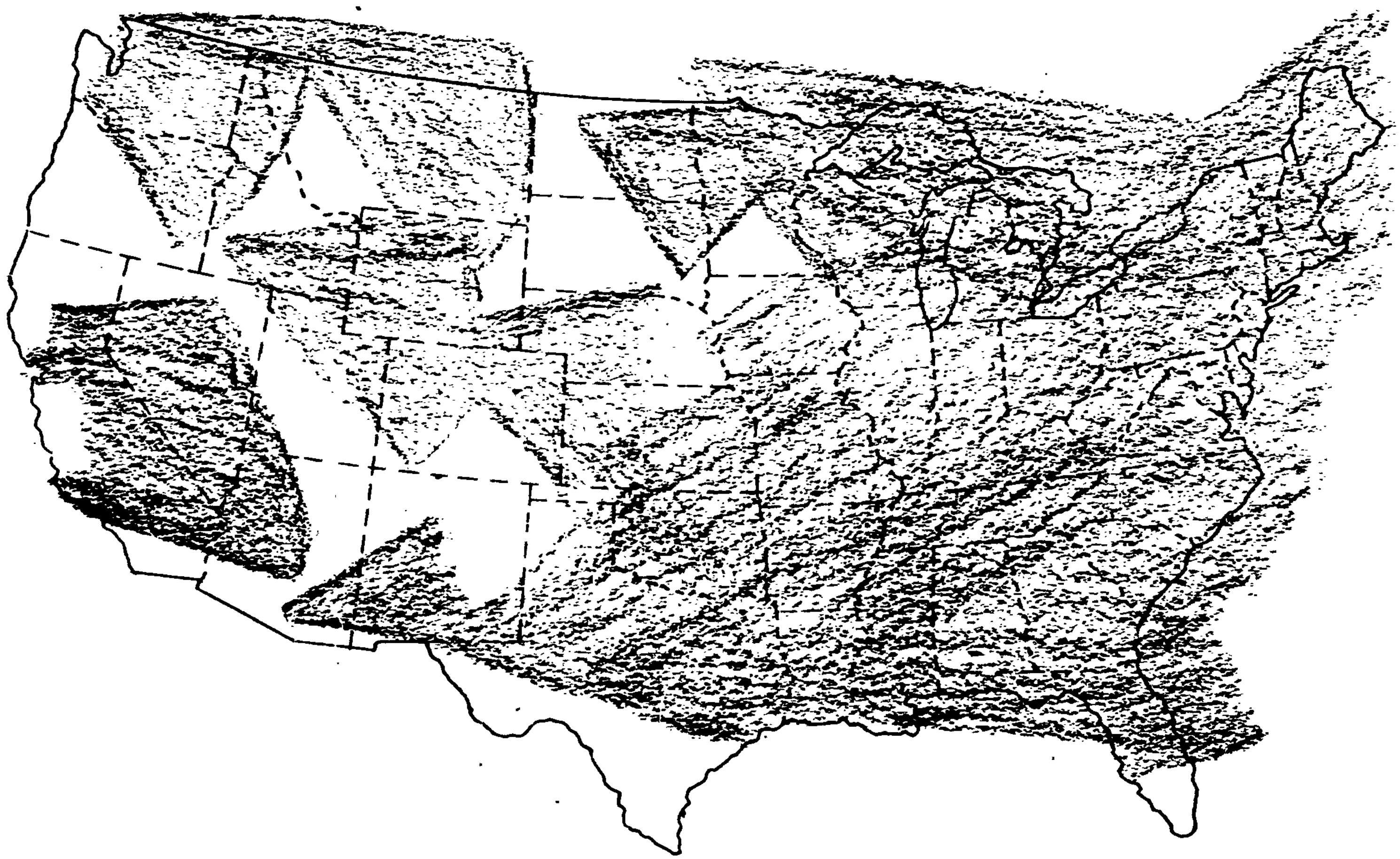


Fig. 4.3 Variation of Fallout Area

made available for critical personnel needed to operate the system. At a distance of 25 miles or more from the predicted impact points the probability of survival from blast or heat radiation from as many as four 5 MT warheads aimed at the target with CEP's on the order of 3 or 4 miles is estimated to be in excess of 99%. Each target in Figure 4.1 is enclosed by a circle with a 25 mile radius. Thus, the area exterior to these circles represents an area of almost certain survival (at least 99%) from blast and heat radiation.

Figure 4.4 shows the locations of non-military airports which are outside the expected damage areas of the target system and which have the capability for maintenance designated as S-5. This is the designation given in the Directory of Aerodromes Available to Military Aircraft to civilian airports that presently have facilities for storage and aircraft and major engine repairs. To estimate operating costs, these airports are assumed to be manned by Air Force recovery units.

The number and distribution of this set of airports indicates that with possibly a few exceptions, there is an airport available within a few miles of where it would be needed for economical operation of a survey system.

The problem of protection against fallout is different from protection from blast and thermal radiation because of the area

S-5 - Storage, major aircraft and major engine repairs.

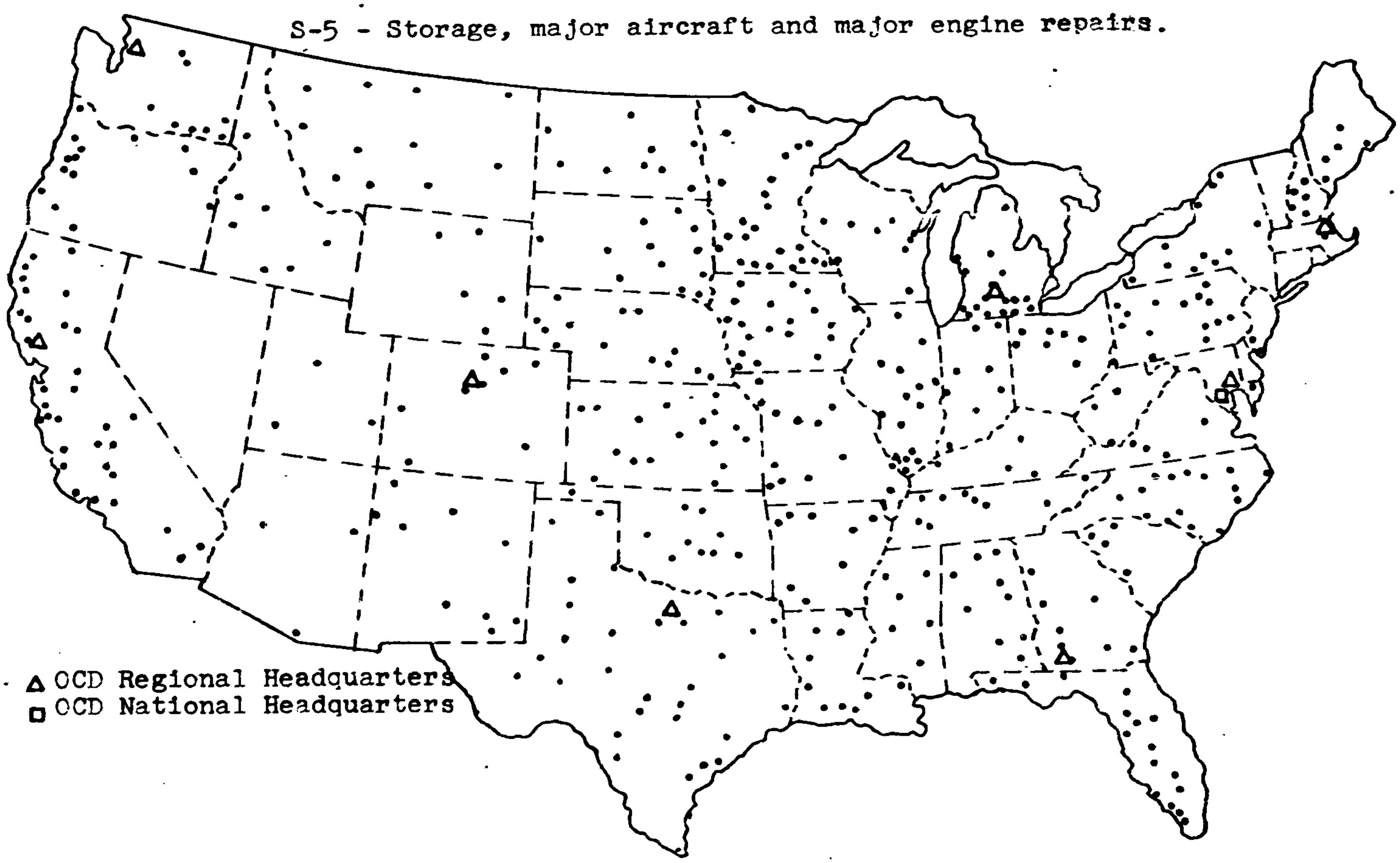


Fig. 4.4 S-5 Aerodromes Available for Bases

involved. All equipment and personnel must be protected. Personnel may remain for a limited time in levels as high as 30–50 R/hr without ill effects. The equipment may also be exposed to these levels and here there is danger of loss of effectiveness due to contamination by fallout particles.

It is emphasized by Figure 4.3 that in the eastern and southern portions of the United States no area is free from expected fallout if bursts fall on the assumed target system. At any time, of course, not all of the area will be covered, but it is not possible to predict with any confidence the location of areas that may escape fallout. Even in the western and central United States, wind directions vary so that fallout can occur almost everywhere.

The following conclusions are made from the previous discussion:

1. The aerial monitoring system should be designed to provide the same degree of monitoring detail and accuracy of radiological data (dose rate levels and flight path spacing) over all section of continental United States. The same remarks would likely apply to the 49th and 50th states, although they were not considered in the analysis.
2. There are enough adequately equipped civilian airports located at a reasonably safe distance from military installations and large population centers (possible targets for nuclear attack) to base the aircraft

for an aerial monitoring system. However, the aircraft, equipment and personnel must be provided with protection from fallout. Possible methods of manning the system in wartime are given in a later section.

5. MONITORING PROCEDURE

5.1 Introduction

The purpose of the aerial monitoring system is to provide the capability to monitor the radiation from fallout resulting from nuclear explosions. The system should be designed to provide the capability to survey the United States following a nuclear war, although, a portion of the system could be used to survey a local area that became contaminated from a peacetime nuclear accident. The system is national in scope and the output of the system is a presentation of the data in the form of dose rate contours drawn on a map of the area surveyed.

Thus, the monitoring procedure must provide sufficient detail to satisfy the needs on a national scale. This does not preclude the capability to provide data useful for regional or even local needs. In the presentation of radiological data on a contour map it is implied that areas free from fallout have been verifed.

It is assumed that the survey will not begin before the early fallout is down. For the case where the nation is subjected to many nuclear bursts, fallout patterns may overlap in many areas, especially in the eastern, southern, and parts of the far western United States. Thus, the time to begin the survey is determined by the level of radiation in the air rather than by cloud passage from a burst. Typically, about 60 percent of the total radioactivity from a ground burst appears as fallout within a period of approximately 12 hours. The remainder stays suspended in the atmosphere for long periods of time so that airborne activity around and below the survey aircraft may be quite intense.

The distribution of isodose rate curves indicates that the flight procedure to monitor a single isolated fallout pattern may be quite different from that required to monitor an area where fallout at a point contains a mixture of radiation from multiple bursts. This is especially true if the location of the burst points are not accurately predicatable.

5.2 Monitoring Levels and Data Required

Three basic technical problems must be resolved in designing an airborne system. First, the radiation on the ground must be reliably determined from measurements made in the air. Second, accurate location of the positions where the measurement were made must be recorded. And, third, these measurements must be scaled to a common reference time to account for the decay of the activity with time.

To solve these problems, the minimum amount of information required for each data point (reading) must include the radiation level in R/hr or an equivalent, the altitude above the terrain, the coordinates of the point at which the reading is taken and the time. The system can be designed to read radiation levels at fixed intervals of time along a flight path or to record the position where preselected radiation levels occur. In either case, there is a compromise to be made between the amount of data needed to construct meaningful dose rate contours and the time required to process the data. Referring to Figure 3.4, it is evident that recording dose rate levels at 1 R/hr increments would require in excess of 1000 points along 40-50 miles of flight path across one fallout pattern. Mindful of the fact that the survey is to be made on a national scale and the resulting contours are to be drawn on a scaled map of the U.S., too many data points would not be meaningful. Thus, in order to reduce the amount of data to be processed it has been assumed that isodose rate lines of 1, 3, 10, 30, 100, 300, and 1000 R/hr are of interest. This range of rates will encompass minimum and maximum values of interest, and other values could be substituted for the intermediate values if conditions of use warranted it.

It is determined in a later section (Section 8) that the set of data points given above will not overload the data transmission system, but recording too many data points may cause the processing time to become intolerably long.

Examination of a set of typical fallout contours (Figs. 3.12 and 3.13) shows that for a flight perpendicular to the wind direction, the dose rate goes from zero to peak to zero in distances varying from 60 to 80 miles. Also, the value of the peak (hot line) can vary from more than 1000 R/hr near the burst point to less than 10 R/hr far downwind. Thus, considering a 400 mph aircraft, the rate at which data is gathered when surveying a single fallout pattern may vary from five points per minute to only one point in six minutes. The number of data points per mile of flight will not be greater than this maximum number when surveying areas covered with overlapping fallout areas. The average value for a series of cuts or for an entire flight may be appreciably less than the maximum.

The number of data points per fallout area is given in Figure 5.1 for various survey spacings. The total flight distance required to survey a fallout area varies from 400 miles up to as much as 1250 miles, depending on wind speed and survey spacing. These numbers refer to idealized plots and may be considerably different for actual fallout patterns.

5.3 Survey Procedure for a Single Burst

The distribution of fallout from a single burst indicates that flight paths crossing the fallout pattern in the crosswind direction would provide a maximum number of useful data points per flight mile. In the crosswind direction, the dose rates change rapidly and the dose rate pattern is symmetrical about the hot line in the sense that the dose rate increases to a

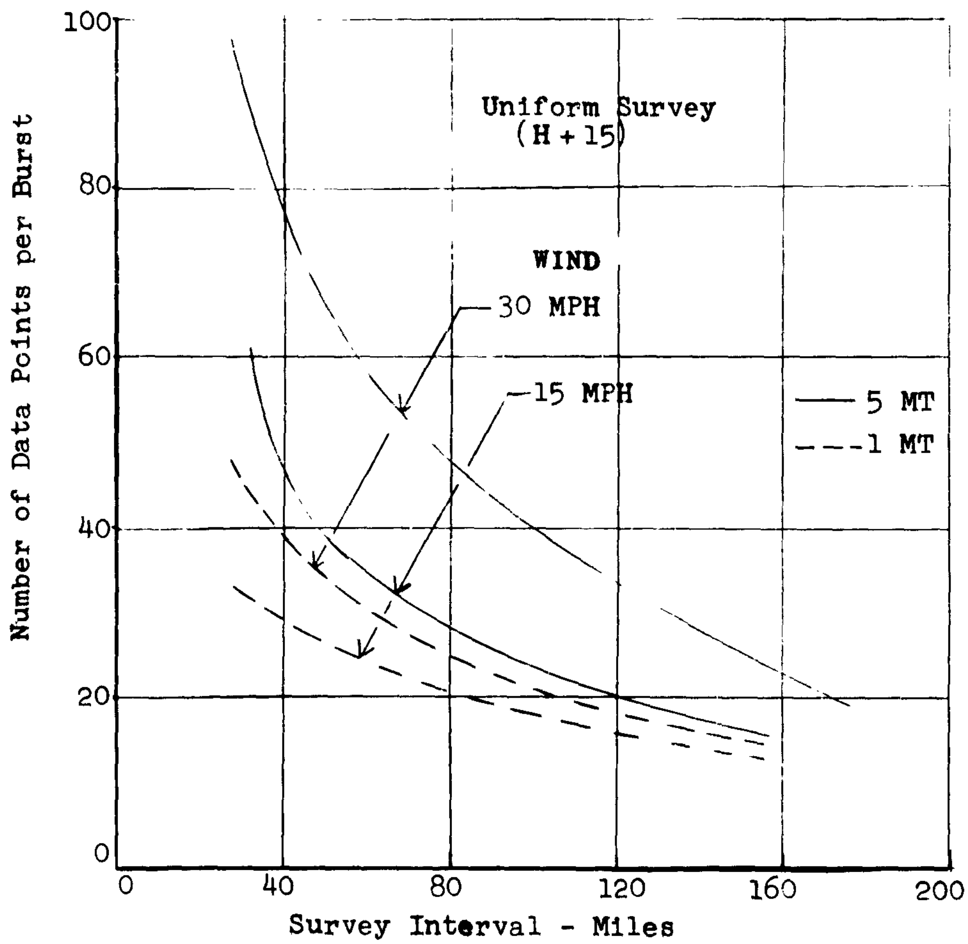
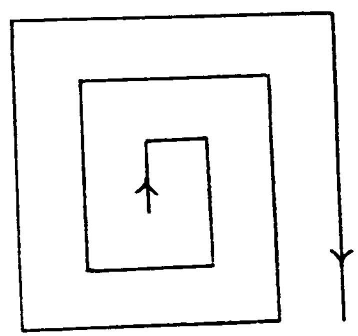


Fig. 5.1 Data Points per Burst

maximum (hot line) and then tapers off to neligible values. Furthermore, each crosswind flight path will intersect the hot line for any spacing between flight paths less than the total downwind length of the pattern.

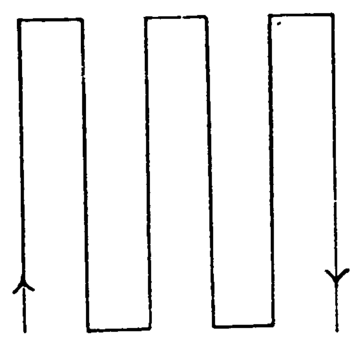
The dose rate of the fallout pattern decreases monotonically in the downwind direction with the exception that isolated hot spots may occur because of some local conditions. The gradient is small, varying with wind speed and distance from the burst point. If survey flights were being made in the downwind direction, only small isodose rate changes per flight mile would be encountered and the chance of intercepting the hot line would be very small. This argument suggests that where a choice can be made (wind information is available), a survey flight pattern where a large percent of the flight is made in the crosswind direction should be chosen.

A spiral, rectangular, or triangular flight pattern (Fig. 5.2) can be used to search for and survey a fallout area. The spiral pattern gives a uniform survey over a square area. To search a rectangular area, the spacing in one direction will be greater than in the other resulting in wasted effort. This pattern is useful in locating the position of a burst point or isolated hot spot in the absence of accurate wind direction. But the spiral is not efficient in making a survey of a fallout area for two reasons. Too much of the survey flight is made in the downwind



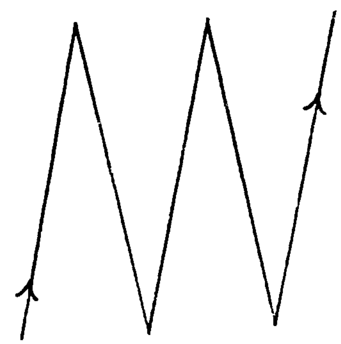
Pattern 1

1. Gives a uniform survey over the whole area
2. Gives a good probability of locating precise burst point and hot spots
3. Is very good when shear winds are present, or wind information is not known



Pattern 2

1. Gives a uniform survey along the wind direction (presupposes a given wind direction)
2. Can be varied during flight
   - (a) Complete coverage of the radioactive area can be made on each pass
   - (b) Path lengths and the distances between them can be varied



Pattern 3

1. Is almost the same as Pattern 2 except the path distance is shorter and the area is not covered as uniformly
2. More complicated navigation problem for changing flight plans during flight

Fig. 5.2 Survey Patterns for a Single Burst

direction and secondly, the data is not being recorded in desirable patterns relative to the contours to be drawn.

The rectangular search pattern is ideally suited for surveying a fallout pattern where the parallel paths are in the crosswind direction. Each flight path intercepts all lines of equal dose rate of the fallout area. The portion of the flight made in the downwind direction is equal to the length of the area being surveyed and much of this may be made outside the fallout area.

The distance between crosswind flight paths can be varied to make the survey as the detailed as desired. The flight paths can be close together near the burst point to give an accurate description of the hot line and the higher dose rate contours; and they can be farther apart as the survey proceeds downwind from the burst where radiation changes are small.

The triangular pattern gives a nonuniform method of covering the area with a shorter flight length and would be used where the location of the fallout area is known. A more uniform pattern should be used in collecting data near the burst point, especially if preselected dose rate levels are being recorded.

Figure 5.3 is an example of the survey of an idealized plot of a 1 MT burst with a 15 mph average wind beginning at (H + 12) hours. The spacing between crosswind paths was varied with downwind distance from the burst point. When making a survey of a fallout pattern that is known to be isolated, a cockpit display of the radiation levels beneath the aircraft gives an indication

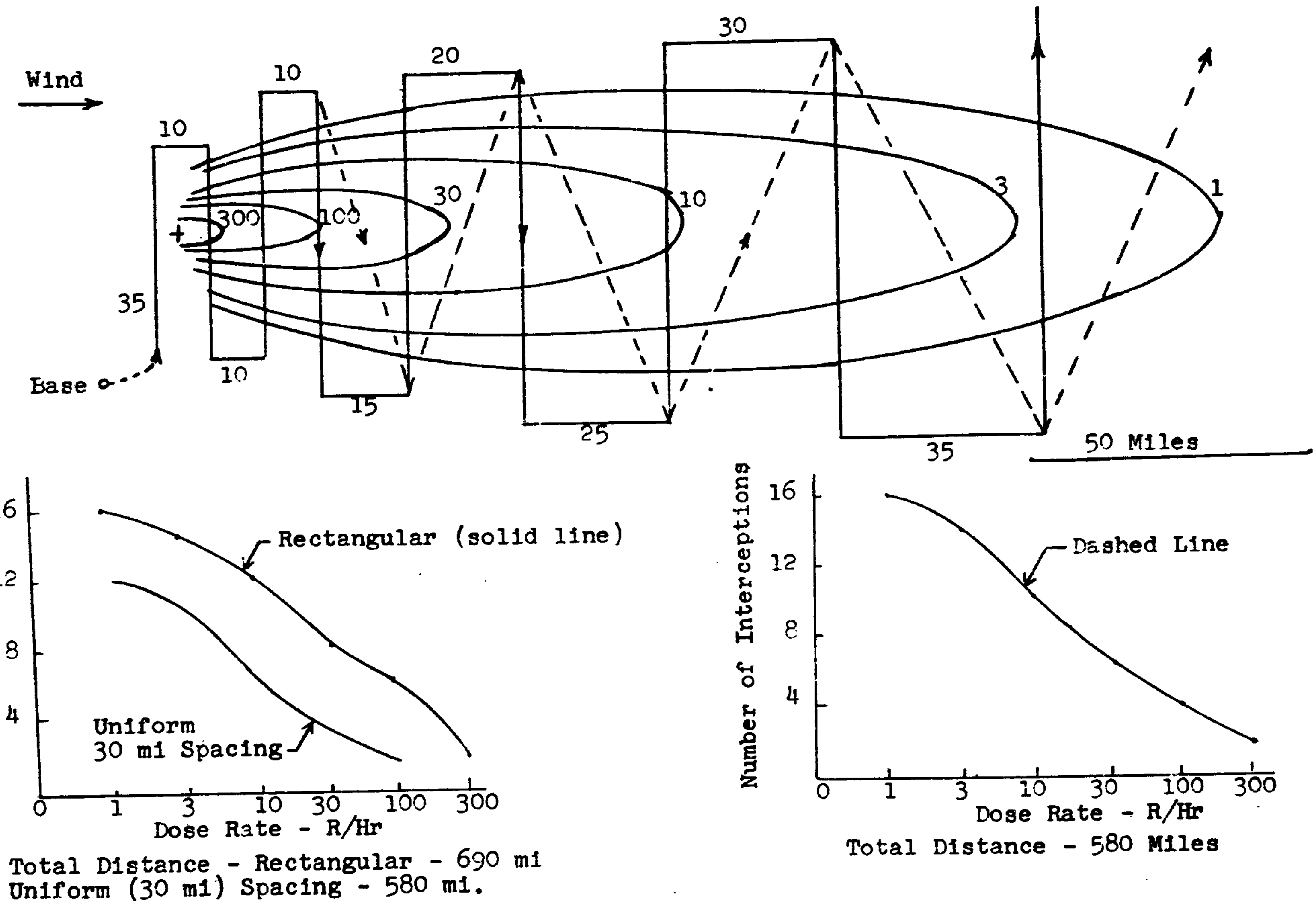


Fig. 5.3 Example of a Survey of a Single Burst
(Survey Begins H + 12)

to the pilot when to turn after crossing the area. The flight path represented by the dashed line is a combination of the rectangular pattern near the burst point and the triangular pattern downwind. Except for the 100 R/hr isopleth, the number of data points is the same for both cases. The distance flown in the triangular survey is approximately 16% less than that for the rectangular.

If a uniform rectangular survey with 30-mile spacing is used, the total distance flown is 16% less than for the variable spacing shown but no data points are recorded for the 300 R/hr rate and only two points for the 100 R/hr line. At the other extreme, if a 10-mile uniform survey is used, the total distance flown is almost two times that for the variable survey. No more data points are recorded for the 100 R/hr and 300 R/hr line but many more are recorded for dose rates lower than 100, where fine detail is less important.

5.4 Survey Procedure for an Area

The distribution of fallout in an area where two or more nuclear bursts contribute to the radiation (Fig. 4.2) is predictable only to the extent that the location of the burst points are known. Although it is expected that Nudets can furnish detonation points, number and yield of bursts, and, to some extent, the time of arrival, neither the design of an aerial survey system nor its operation should be based upon the survival or output of that system. Consequently, in the absence of detailed and accurate knowledge of the number and location of bursts, a uniform survey pattern is required in areas where a high density of bursts is expected. The rectangular flight pattern is best for a uniform search of an area. The distance between flight paths, and consequently, the area that can be surveyed by an aircraft, depends upon how important it is to intercept a given R/hr line. The two distinct types of flight patterns considered in this study are shown in Figure 5.4. In each, north-south movements are considered to be the primary data gathering flight directions although some information will, of course, be collected during east-west movements.

Method A is more economical in range, but has two major disadvantages. First, each aircraft must be located at a separate base, where the landing base for one is the take-off base of the next in the chain. The result is a loose knit organization from the standpoint of both administration and peacetime training exercises. Secondly, if bases are not available near the survey flight range of the aircraft, excessive range is lost.

Method B differs from Method A in that each aircraft returns to its own base. Thus, each airplane makes two east-west flights over the area instead of one which decreases the amount of aircraft range available for survey purposes. On the other hand,

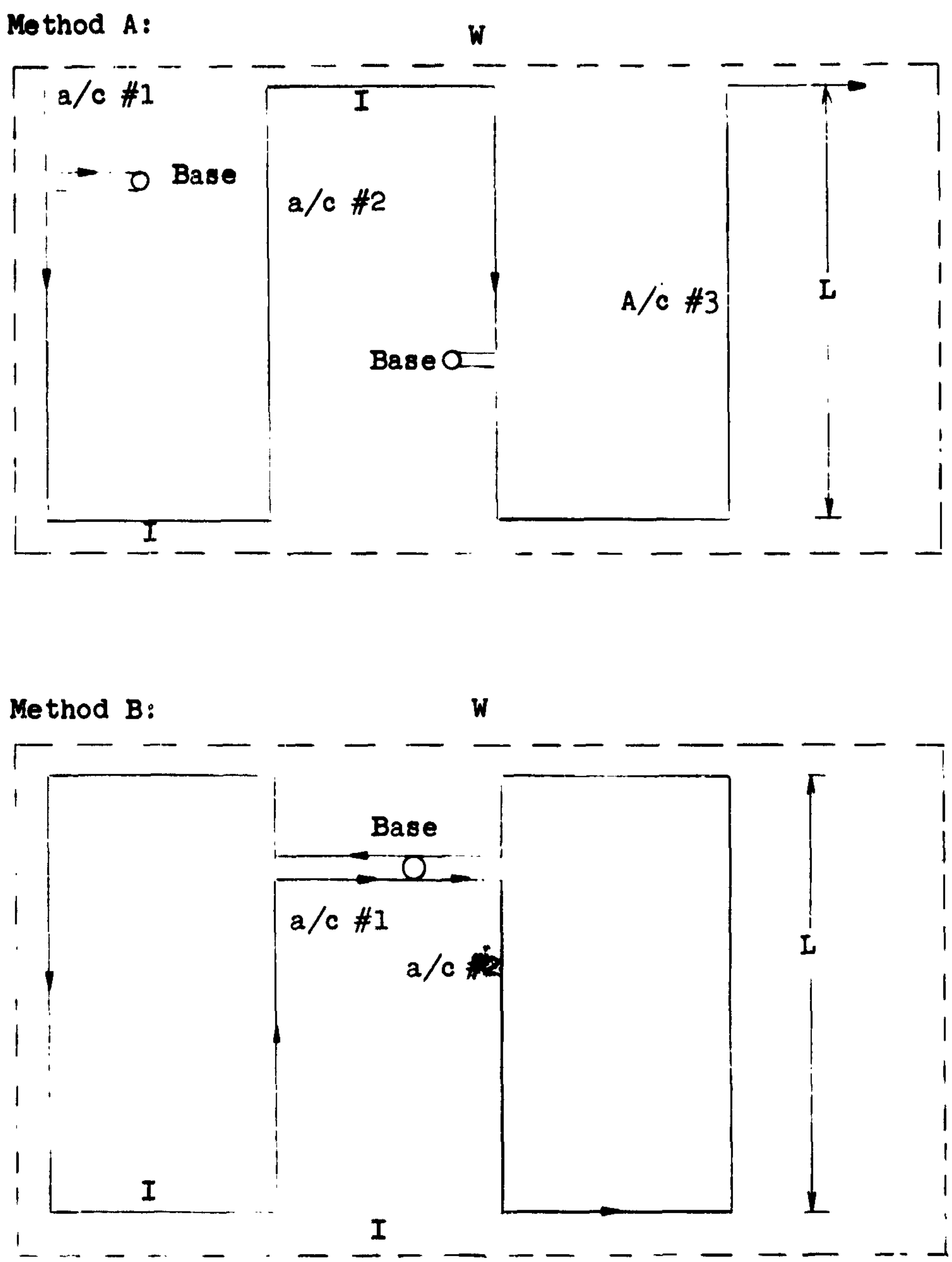


Fig. 5.4 Equal Coverage Flight Patterns

in Method B a base can be located anywhere along the line L so that a suitable base is more likely to be found closer to where it is needed. Consequently, less distance (aircraft range) is wasted going to and returning from the survey flight path. In this method, two aircraft can be located at a base, and if a base is available at the top or bottom of the survey area, four aircraft can use the same base.

5.4.1 Model for Survey Method A

It is convenient to regard flight patterns in terms of rectangles of length L (north-south direction) and width W. A series of such rectangles, or a single one, are made to fit the country without too much waste at the boundaries, although some ocean coverage is desirable. Then for each rectangle, the distance D to be flown is given by

$$D = \frac{WL}{I} + (W-I)$$

where I is the distance between successive north-south movements.

Here W/I gives the number of monitoring paths used to cover the rectangle and (W-I) is the total distance covered between monitoring cuts (east-west movement).

If bases could be located as desired, then the number of aircraft required to monitor a rectangle would be D/R, where R is the aircraft range. However, bases must not only have complete repair and maintenance facilities but they must also be located away from expected target areas to ensure high survivability. It is estimated that a base which satisfies these criteria could be found within a 50 miles radius of any required position.

Thus, the number N of aircraft required per rectangle is

$$N = \frac{D}{R-100} - \left[\frac{WL}{I} + W-I\right] \frac{1}{R-100}$$

and the number of bases is N + 1.

The time required to collect the data is given by R/v where v is the survey speed of the aircraft. To find the number of aircraft required to survey the U.S. using Method A, the area is divided into convenient rectangles and an N is determined for each rectangle and flight separation distance, I.

The variation in number of aircraft required to monitor the U.S. with changing aircraft range and monitoring intervals is shown in Figure 5.5. The variation with time is shown in Figure 5.6. It can be seen that long ranges are best from the point of view of number of aircraft but worst when time to monitor is considered. The dashed lines show the effect of the choice of the distance L on the number of aircraft required. As L decreases, the number of aircraft increases because more east-west travel is required.

5.4.2 Model for Survey Method B

In survey Method B, the variables of choice for a given survey path spacing are the dimensions of a rectangle associated

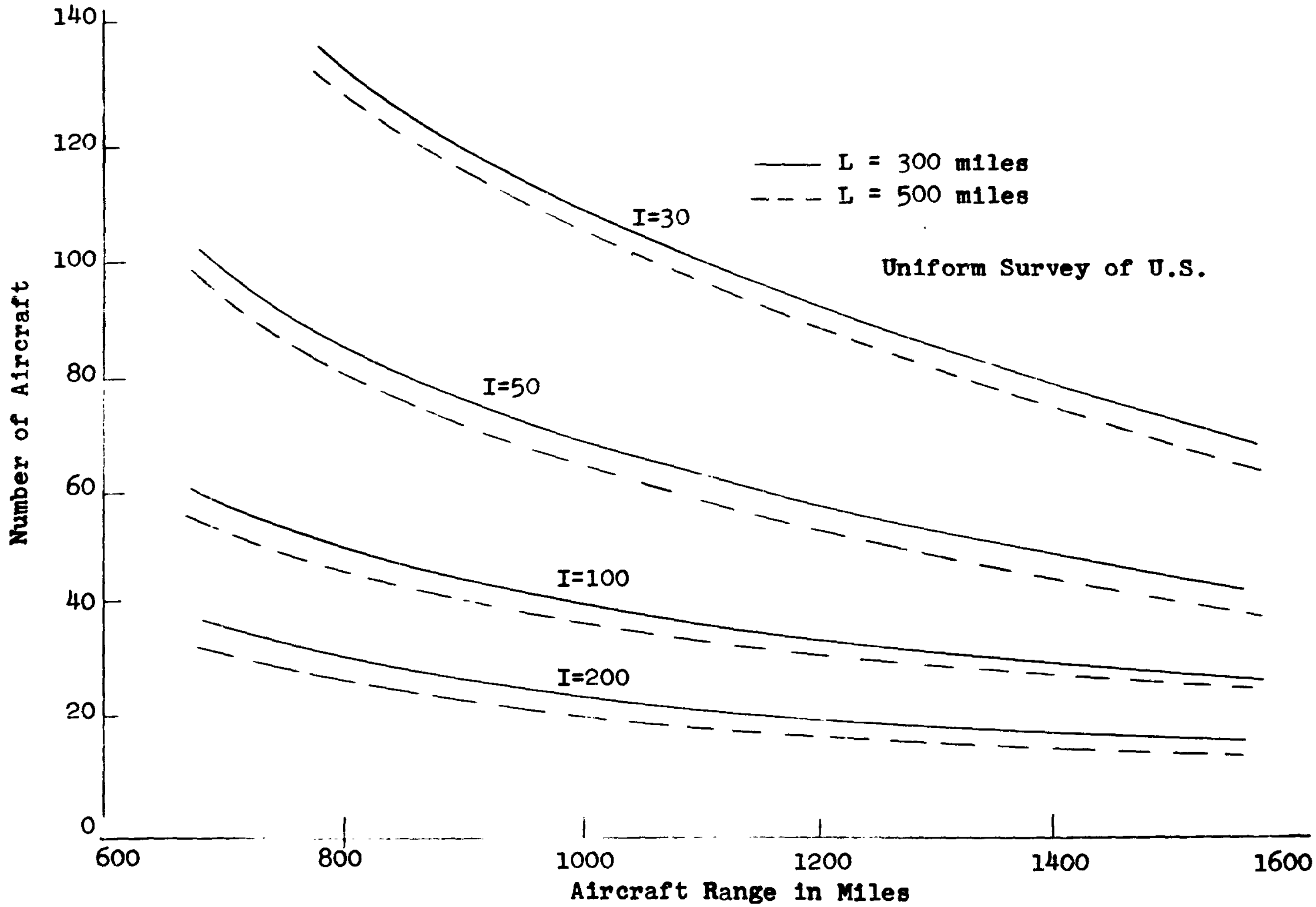


Fig. 5.5 Survey Aircraft Requirements Using Method A

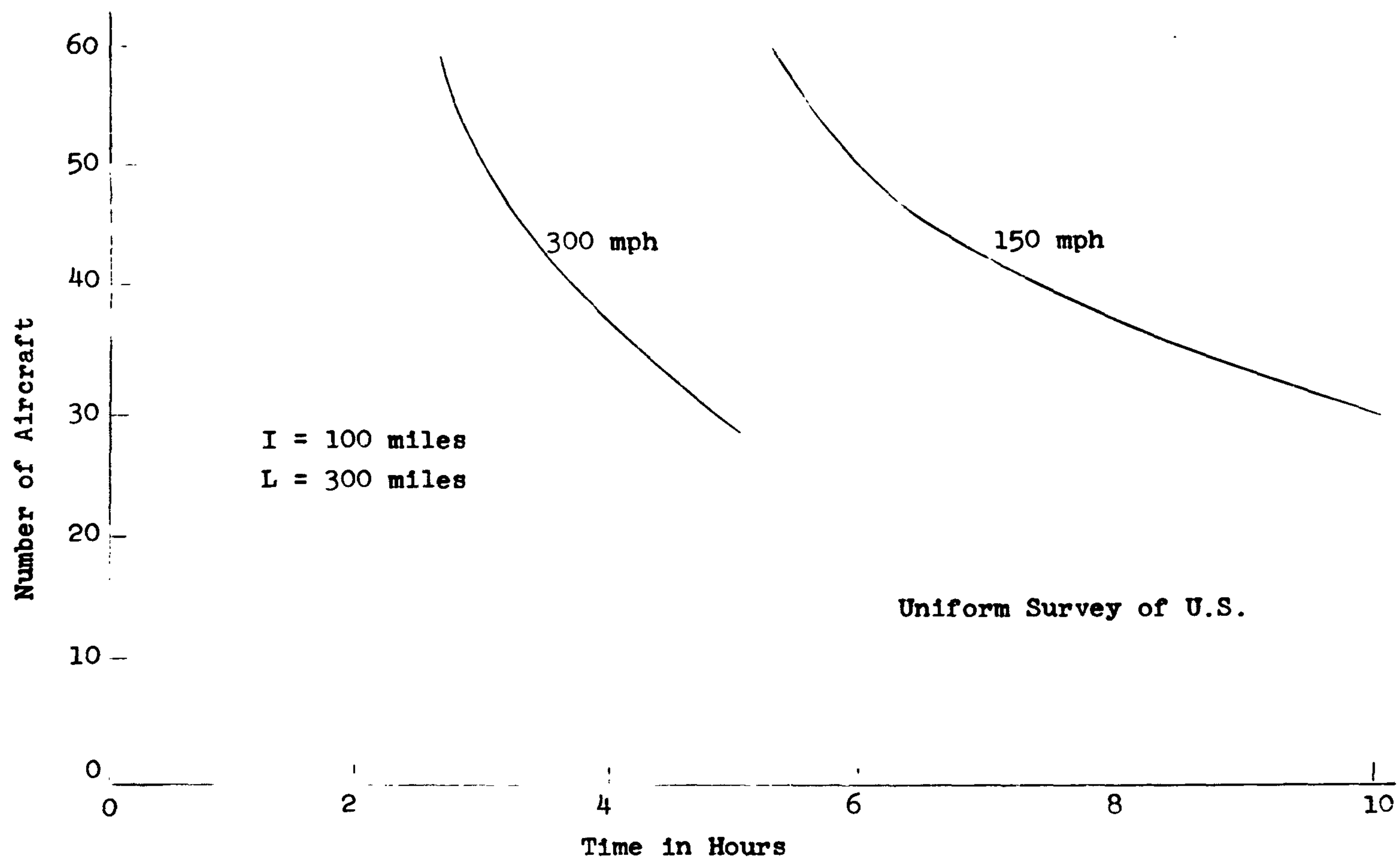


Fig. 5.6 Data Collection Time Using Method A

with each aircraft range and the number of survey cuts assigned to each. Three cases are shown in Figure 5.7 where n is the number of survey paths per aircraft per rectangle. It can be seen that in each case, a base can be located anywhere along the length L without changing the survey flight distance of the aircraft. An average of 60 miles is allowed for the off course variation of the location of available bases from where they are needed. This is 30 miles on either side of the centerline parallel to a length L.

From the geometry of the figure, the range of an aircraft is given by

$$R = nL + (2n-1)I + 60 \qquad n = 2, 4, 6, \ldots$$

and

$$R = nL + nI + 60 + \sqrt{L^2 + \left[(n-1)\ I\right]^2} \quad n = 1, 3, 5, \ldots$$

where

n = number of north-south paths

I = distance between paths

L = length of the rectangle being surveyed

The width W of the rectangle controlled by each aircraft is

W = nI.

This method permits the use of two aircraft per base and the area of base responsibility is a rectangle with dimensions L x 2nI. From the relationship between R, L, and W, it is seen that there is a variety of dimensions of rectangles for each aircraft range and path spacing I. Consequently, the area that an aircraft can survey will vary with the number of cross flights, n.

A comparison of the survey efficiency of the cases shown in Figure 5.7 is made in Table 5.1 for a 1000 mile range aircraft and a 60 mile survey separation distance.

Table 5.1

EFFICIENCY COMPARISON

	n = 2	n = 3	n = 4
Survey Area Aircraft (sq. mi.)	45,600	32,400	31,200
Efficiency (area/flt. mi.)	45.6	32.4	31.2
Percent Effective	100	71	68

These results show that, disregarding other constraints, rectangular survey areas determined by n = 2 are preferred, by n = 3 is next, and so on. It is noted that the number n also determines the shape of the rectangle where a small n gives a long narrow north–south oriented rectangle and a large n makes the orientation in the east–west direction.

The number of aircraft required to monitor a given area using Method B can be found from a map exercise. The given area is covered with rectangles whose dimensions are computed using various values of n for a given aircraft range, R, and survey spacing, I. The most economical system from the standpoint of number of aircraft is found by using as many rectangles as possible with n = 2, then with n = 3, and so on, until the area

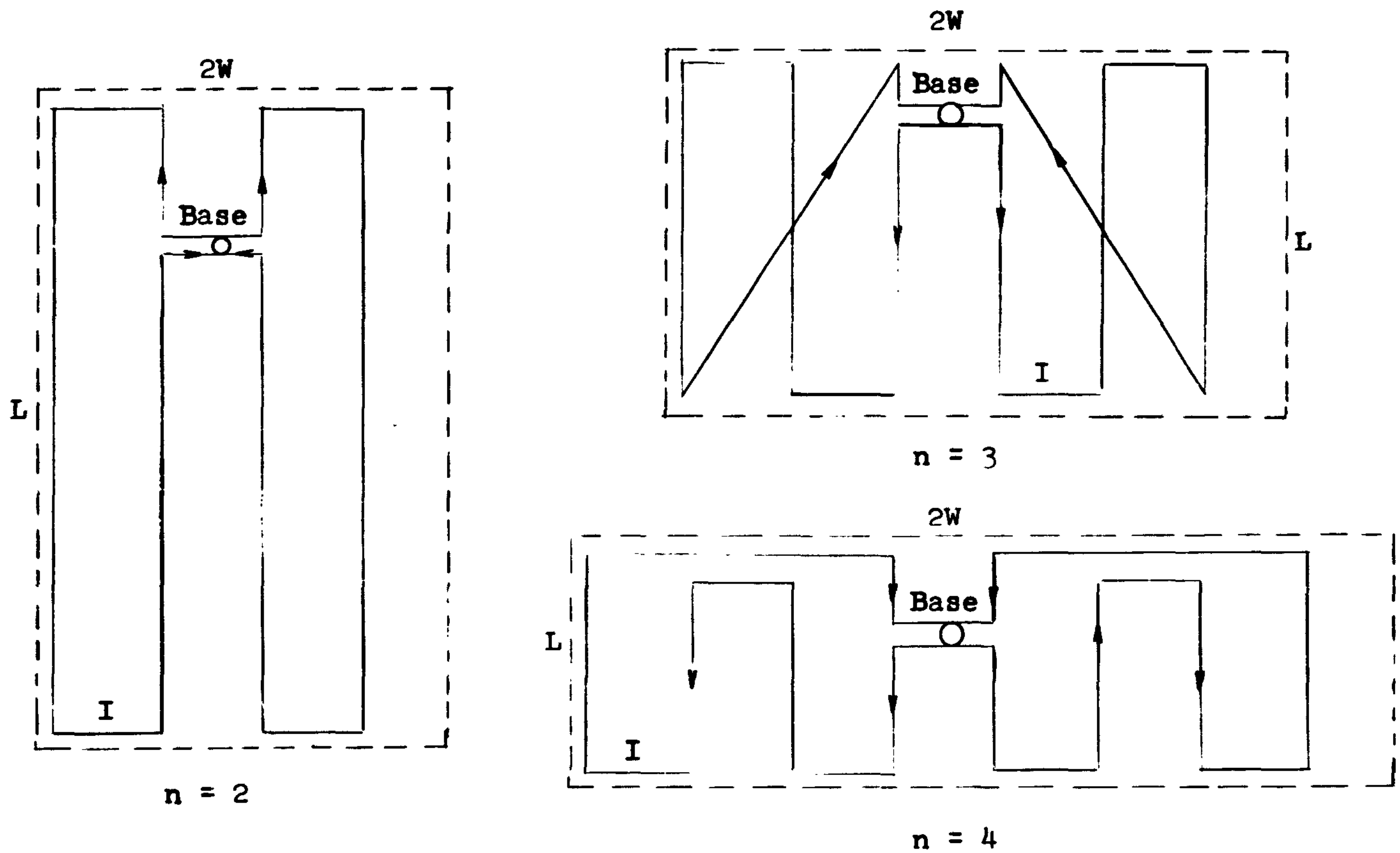


Fig. 5.7 Method B Survey Patterns

is covered. Irregular shaped areas are covered with rectangles whose dimensions are found for the best choice of n. The relationship between aircraft range and the number of aircraft required to monitor the U.S. is given in Figure 5.8 for different values of I.

An example of a map exercise for a survey of the U.S. is shown in Figure 5.9. The distance between the primary data collection flight paths is 60 miles. Two aircraft with a 1230-mile range are assigned to each rectangle except for three areas which require only one. A total of 57 aircraft is required for this system.

Figure 5.10 is an expanded view of rectangle A in Figure 5.9 showing survey paths relative to four fallout areas and a typical base location. The 60-mile separation distance survey intercepted the 100 R/hr and 300 R/hr line of one burst and the 100 R/hr line of another. It is not difficult to visualize the importance and usefulness of readings on the hot line in locating the points where the 300, 100, 30, and 10 R/hr contours close in two of the areas.

The preceding discussion shows that it takes more aircraft to survey a given area using Method B than using Method A, and the difference will vary with the shape of the area to be surveyed. However, Method B has many advantages over Method A which cannot be measured quantitatively. There is an operational

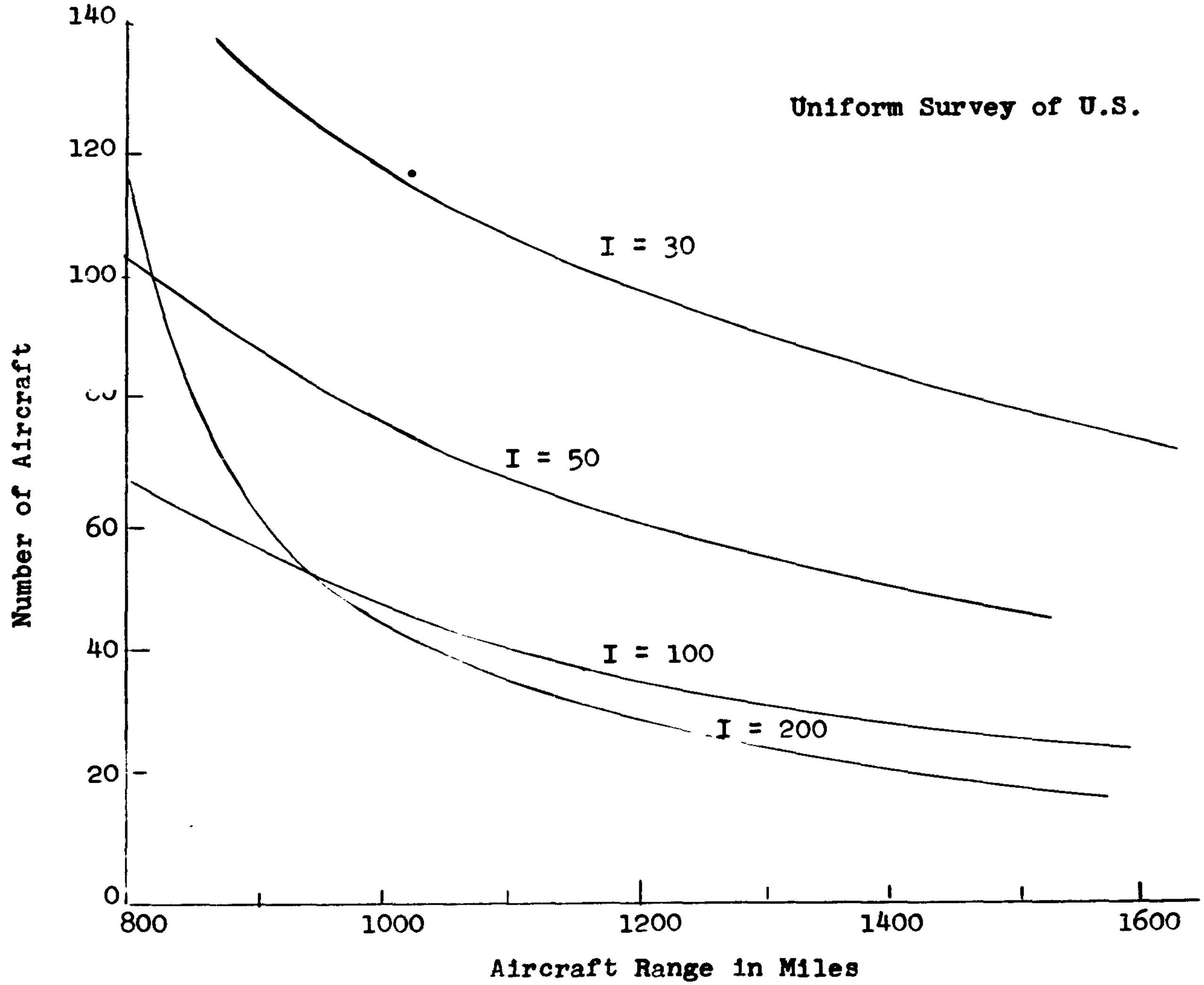


Fig. 5.8 Survey Aircraft Required Using Method B

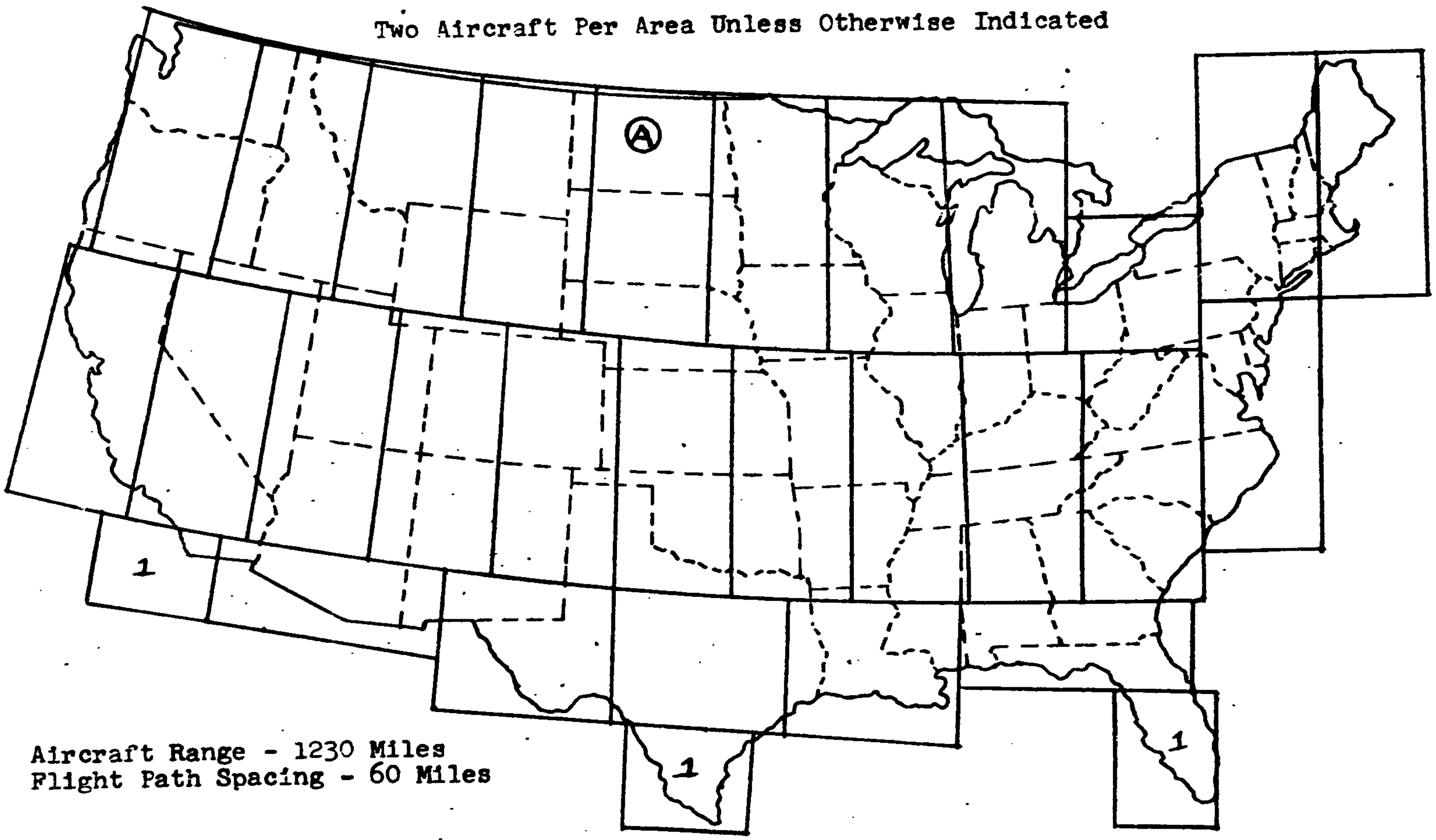


Fig. 5.9 Survey Areas

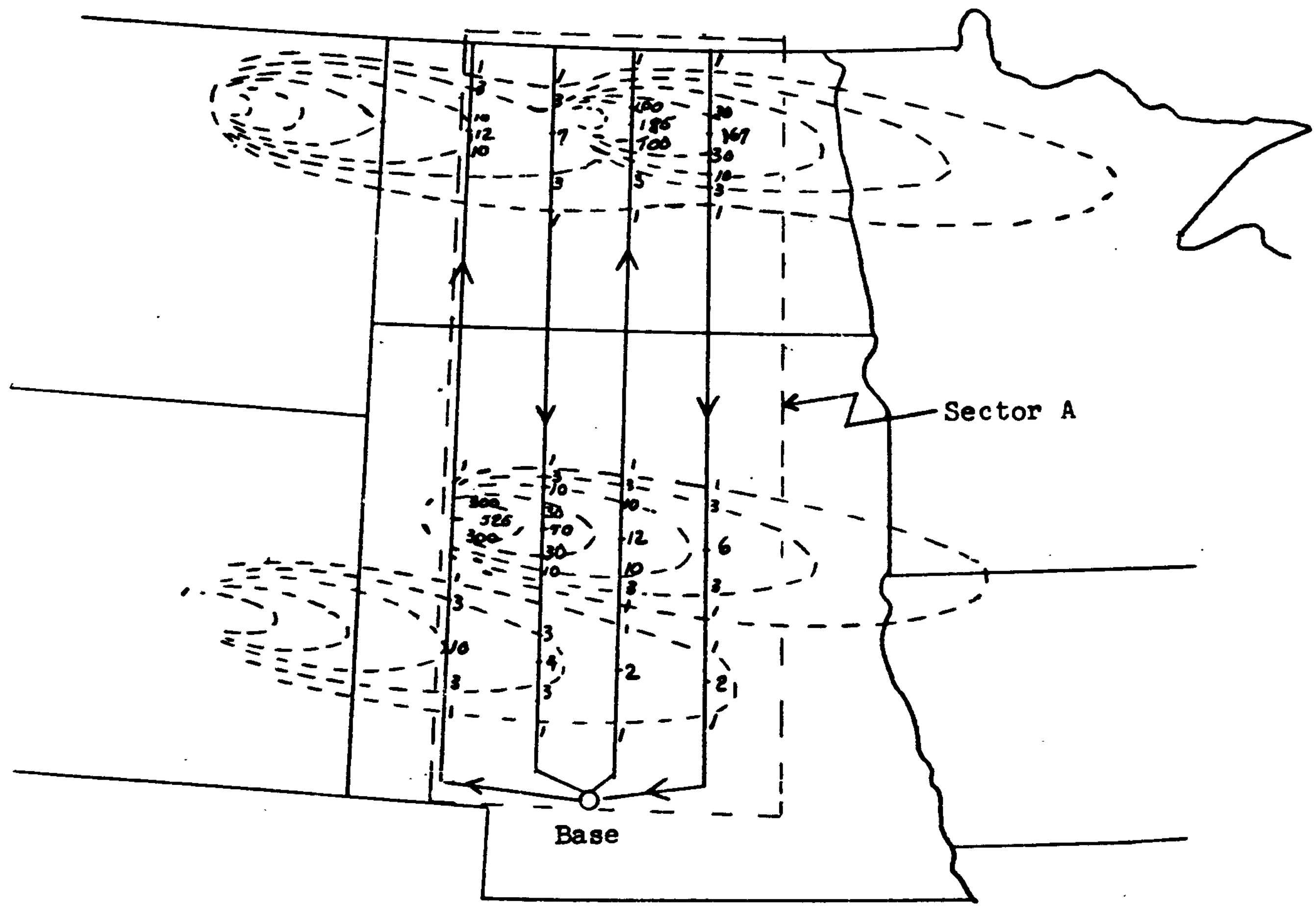


Fig. 5.10 Survey Details

flexibility associated with Method B that Method A does not have. Each aircraft is assigned to survey a given rectangular area based upon a specific flight pattern with respect to an expected fallout pattern. If, in local areas, fallout conditions are appreciably different from the expected, an aircraft can make the survey of the area assigned to it using an appropriate flight pattern for the new conditions. There are fewer operational units with Method B than with Method A since two or more survey aircraft can operate from the same base with Method B. Thus, the administration, training, manning, and operational functions are easier to coordinate with the fewer units. Furthermore, operational units consisting of two or four aircraft and associated ground support may be more economical to operate during peacetime.

5.5 Drawing Isodose Rate Contours

For the purpose of describing the construction of a set of isodose rate contours, we consider an idealized fallout area resulting from a single burst. The survey flights are being made in the cross wind direction. The position of the data points are being plotted at points where preselected radiation levels occur on the ground. Thus, readouts include only isodose rates of interest which reduces the plotting and interpolation problems.

Each flight through the area provides data points for all preselected levels less than the value at the hot line. The value at the hot line is also recorded. Obviously, the number of data points collected by the system for each fallout pattern will depend upon the number of cross flights through the area.

A typical example of the collection of data points for five flights is shown in Figure 5.11. The 300 R/hr isoline was intersected only once giving two points for the contour. There are six 100 R/hr, eight 30 R/hr, and ten 10 R/hr points recorded and the hot line was intercepted on each cross flight. The long side of the isodose rate lines can be quite accurately described by connecting points on the contours of lesser values where several points are available. For instance, in the example shown there are ten points, five on each side of the hot line, to describe the long side of the 10 R/hr contour. This contour, drawn first, aids in constructing contours for the higher dose rates where fewer points are available. The down wind extent of each isodose rate of interest (the preselected set) can be determined by a simple interpolation between the values recorded on the hot line. Consequently, each contour can be closed in the down wind direction at points whose positional accuracy is determined by logarithmic interpolation.

It is expected that smooth curves will be used to connect successive points around a contour, smoothing out irregularities caused by local conditions. If more detail concerning the position of a contour between two flights paths is needed, the

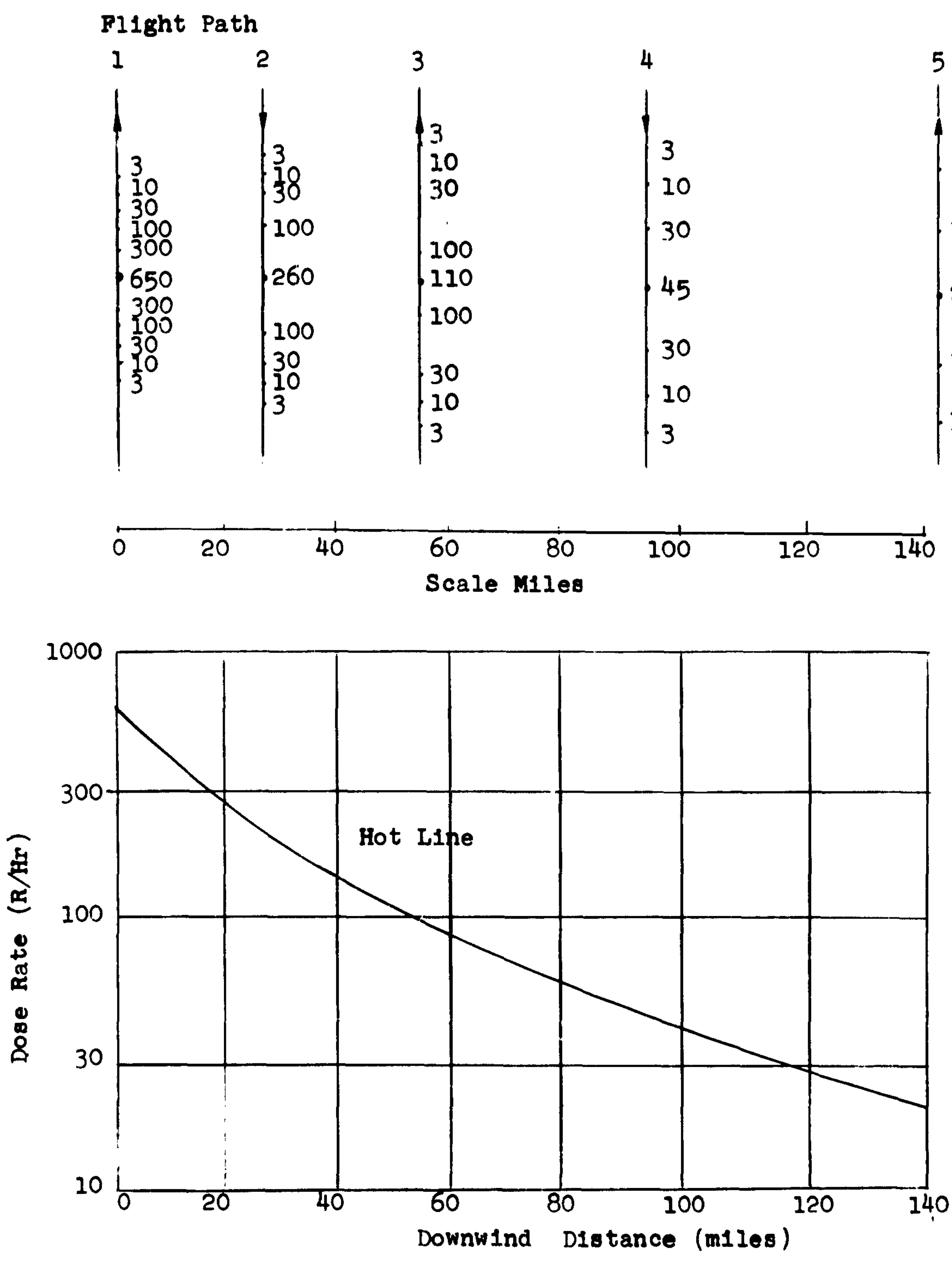


Fig.5.11 Contour Data Points

survey must be made in more detail, requring that cross flight paths be closer together.

It can be seen that if the hot line is a monotonic function, the contours can be closed much more accurately by using interpolated points on the hot line than by increasing the number of cross flights to collect more data points. The probability of intersecting a given isodose rate line within a few miles of its extremity is very small. Isolated hot spots can be distinguished by the non-monotonic variation of the hot line, provided the entire hot spot does not fall between two successive cross flights.

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Ref. 2 J. E. H nd, R. B , Guillou, H. M. Borella, "Aerial Radiological Monitoring System, Part II, Performance, Calibration, and Operational Checkout of the EG and G ARMS-II, Revised System," Atomic Energy Commission CEX-59.4, Edgerton, Germeshausen and Grier, Inc., October 1962. (U)

Ref. 3 S. Glasstone, "The Effect of Nuclear Weapons," United States Atomic Energy Commission, April 1962. (U)

Ref. 4 Radio Facility Charts, U.S Air Force and U. S. Navy,

6. RADIATION EXPOSURE TO AIRCRAFT CREW

The total dose received by unprotected personnel in the survey aircraft was calculated for single traverses along and across an idealized fallout pattern 12 hours after a 1 MT burst. The traverses are taken to pass directly over ground zero, as shown in Figure 6.1.

According to Figure 6.1, the maximum dose expected for a traverse at 2200 feet is about 0.01 R. The dose received in a single traverse is not hazardous.

Whatever air contamination is present will contribute to the dose received by the aircraft crew. In the situation described in Section 3.2.1, the dose rate due to contaminated air will be approximately 0.004 R/hr. The dose contribution from the air may, then, be expected to be rather small compared to that from the ground.

It is mentioned in Section 4 that survey aircraft equipment and personnel must be protected from fallout since a survey cannot begin until most of the fallout is down and the deposition of fallout cannot be predicted with any degree of accuracy. For the same reasons, the aircraft and crew can be exposed to various radiation levels for short periods of time during taxi, take-off, and landing.

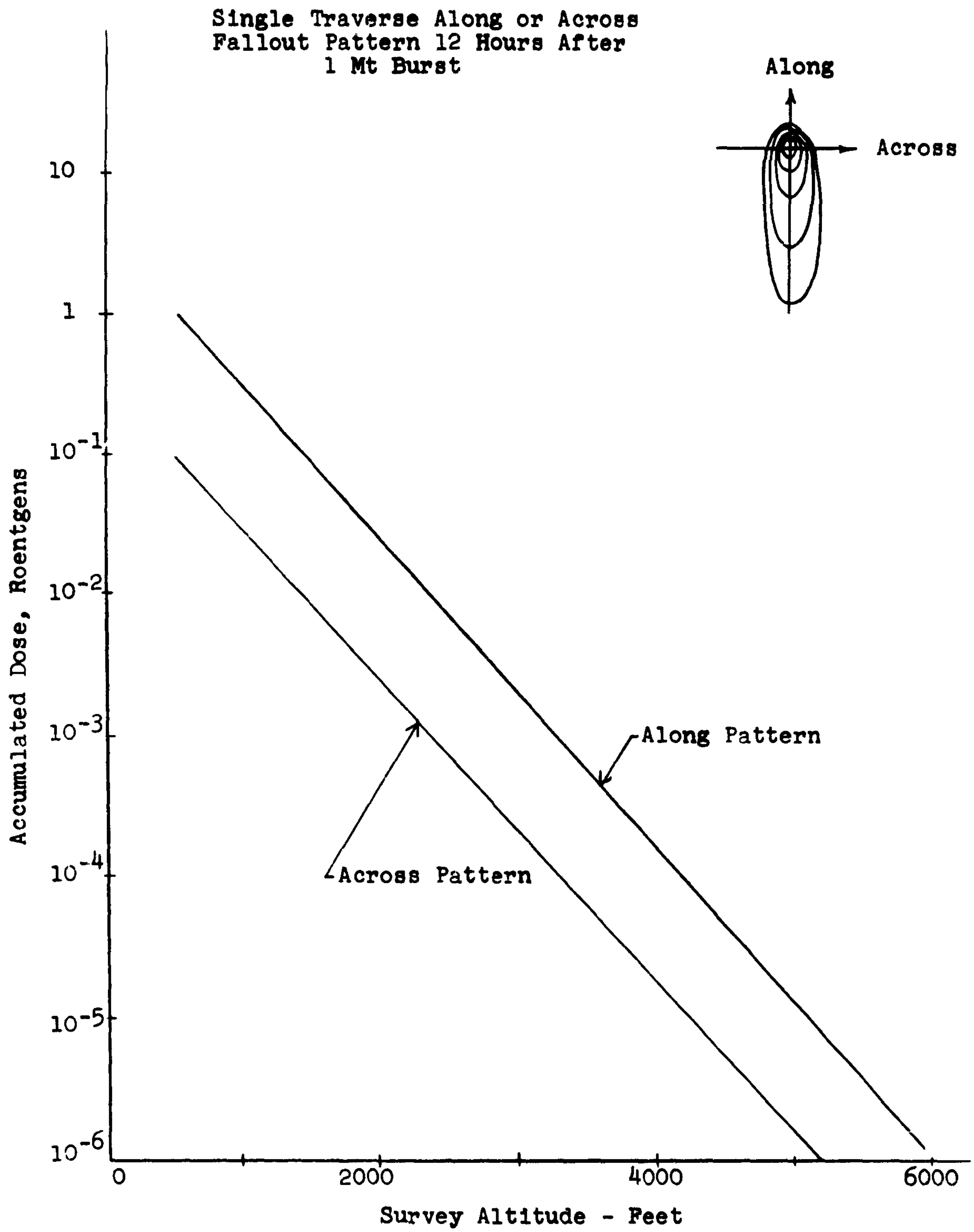

Fig. 6.1 Dose to Aircraft Crew Without Protection

The amount of shielding, if any, required for crew protection will depend in detail upon the survey pattern and the total exposure time during the survey. A typical mission during a saturation attack should expose the crew to considerably less than a 20 R/hr mission dose.

The dose which might be received as the aircraft itself collects contamination may reach a few R/hr. However, the unknown relation between the specific activity of the air and the buildup on the aircraft preclude analysis of this hazard at the present time.

7. SENSOR DESIGN

7.1 Introduction

Radiation from fallout on the ground is to be detected quantatively in the presence of background by a detector some distance above the surface of the earth. The fallout dose rate at ground level is to be inferred from the radiation intensity at the detector.

In arriving at a preliminary design for a practical detector, it is assumed that system accuracy shall not be limited by detector characteristics as such. That is, the detector is to measure the γ-ray flux at the detector position with an accuracy which is greater than the accuracy with which the flux at that point is known to be related to the ground dose rate.

Detector requirements may be estimated in terms of

(a) gamma-ray flux (at altitude) due to sources on ground

(b) background intensity at altitude

(c) desired accuracy of the system.

A sodium iodide scintillation detector will be used, and its output will be fed into a ratemeter to develop an analog indication of the γ-ray flux at the detector. Use of such a detector and ratemeter is desirable because the equipment is readily available, and produces an analog output convenient for subsequent processing in the system computer. These equipments together will be referred to as the detector channel.

The following sensor design is recommended: Two shielded scintillation detectors facing 180° apart, one open toward the ground, the other open to the sky. The cone of acceptance of each detector has a half angle of 45°. The outputs of these detectors are opposed in such a way as to compensate for background. Each detector consists of a sodium iodide crystal in the shape of a right cylinder, 2" long with a crossection of 1.25 cm^2, mounted on a type 6199 photomultiplier or equivalent. The time constant of the ratemeter is 1.4 seconds.

This design will permit the measurement of the 1 R/hr isopleth with a 10:1 signal-to-noise ratio while flying at 2200 feet altitude and will permit the tracking of the maximum rate of change in gamma flux while crossing isopleths at a speed of 340 kts at an altitude of 500 feet. The system accuracy for measurement of the gamma flux at 2200 feet altitude is $\pm 10\%$ with a confidence level of 68.3%.

7.2 Sensitivity and Accuracy of Detector Channel

For the γ-ray energies of interest here, the efficiency of a practical detector may be assumed to be 100% (see Appendix C). The direct output of the detector is a train of pulses occurring at an average rate

$$\bar{N} = \bar{\phi} A \text{ sec}^{-1} \qquad (1)$$

where $\bar{\phi}$ is the (average) γ-ray flux at a detector with effective area A. It is necessary to consider the average quantities $\bar{N}$ and $\bar{\phi}$; rather than instantaneous values N and ϕ, because of the statistical nature of the processes which produce radiation; N and ϕ are predictable only statistically from $\bar{N}$ and $\bar{\phi}$ (see Ref. 7.1, Ch. 26).

7.2.1 Ratemeter Accuracy

The indication of a calibrated ratemeter will be N and have a standard deviation (Ref. 1, p. 803)

$$\sigma(N) = \sqrt{\frac{1}{2} \bar{N}\tau} \qquad (2)$$

where τ is the time constant of the instrument. The fractional standard deviation of the ratemeter indication is

$$\sigma_f = \frac{\sigma(N)}{\bar{N}\tau} = \frac{1}{\sqrt{2\bar{N}\tau}} \qquad (3)$$

7.2.2 Separation of Signal and Noise

Now, in general, ϕ and $\bar{N}$ will be the sum of contributions from fallout on the ground (the signal) and from background (the noise). As shown below, however, it is possible to arrange a pair of detectors so that one will respond to noise plus background, while the other responds to background alone. The difference between the indications of these two detector channels will be indicative of the signal from the ground.

Denote by $\bar{N}_s$ the "true" signal, i.e., that which would be observed with no background. Let $\bar{N}_B$ be the background as determined by the background detector channel. Let $\bar{N}_{Bs}$ be the sum of signal and background as determined by the main detector channel. Let Δ be the difference between the observed outputs of the two detector channels,

$$\Delta = N_{Bs} - N_B \tag{4-a}$$

and

$$\bar{\Delta} = \bar{N}_{Bs} - \bar{N}_B \approx \bar{N}_s \tag{4-b}$$

The question now is that of how accurately the difference, Δ, between N_{Bs} and N_B, reflects the mean signal $\bar{N}_s$. It can be shown that the standard deviation of Δ is

$$\sigma(\Delta) = \sqrt{\sigma^2(N_{Bs}) + \sigma^2(N_B)}. \tag{5}$$

Let the signal-to-noise ratio be

$$S = \frac{\bar{N}_s}{\bar{N}_B},$$

so that equation (5) may be written as

$$\sigma(\Delta) = \left[\left(\frac{1}{2}\bar{N}_s\tau\right)\left(1 + \frac{2}{S}\right)\right]^{1/2} \tag{6}$$

The fractional standard deviation for Δ is

$$\frac{\sigma(\Delta)}{\bar{N}_s \tau} = \frac{1}{\sqrt{2\bar{N}_s \tau}} \left(1 + \frac{2}{S}\right)^{1/2}; \qquad (7)$$

substituting $\bar{\phi}$ A for $\bar{N}_s$ according to equation (1),

$$\frac{\sigma(\Delta)}{\bar{N}_s \tau} = \frac{1}{\sqrt{2 \bar{\phi}_s A \tau}} \left(1 + \frac{2}{S}\right)^{1/2}. \qquad (8)$$

The fractional error in the measurement of N_s by differences of N_{Bs} and N_B is thus

$$\epsilon = \frac{K\sigma(\Delta)}{\bar{N}_s \tau} = \frac{K}{\sqrt{2 \bar{\phi}_s A\tau}} \left(1 + \frac{2}{S}\right)^{1/2} \qquad (9)$$

where K is the number of standard deviations associated with the desired confidence limits:

K = 0.675	conf. limit = 0.50
1.00	= 0.683
2.00	= 0.955
3.00	= 0.997

Finally, the quantity $\bar{\phi}_s A$ is found from (9)

$$\bar{\phi}_s A = \frac{(S + 2)K^2}{2S \epsilon^2 \tau} \qquad (10)$$

In Figure 7.1, $\bar{\phi}_s A$ is shown as a function of S for various values of K/ϵ, and $\tau = 1.4$ sec, a reasonable value of situations

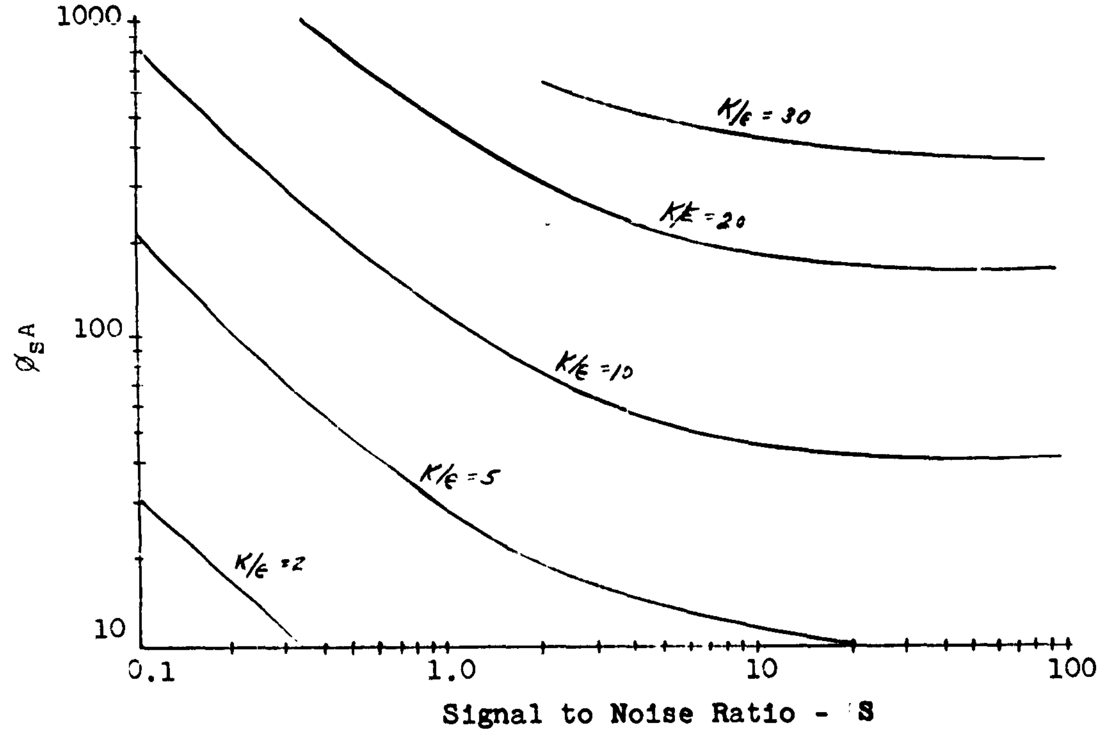

Fig. 7.1 $\phi_s A$ Versus Signal to Noise Ratio for Different K/E

of practical interest. Similar data are given in Table 7.1 where confidence limits and percent error are related to K/ϵ.

Table 7.1

CONFIDENCE LIMITS AND PERCENT ERROR FOR VARIOUS VALUES OF K/ϵ

K/ϵ	K	C.L.	ϵ(%)
2	1	68.3%	50%
	2	95.5%	100%
	3	99.7%	150%
5	1	68.3%	20%
	2	95.5%	40%
	3	99.7%	60%
10	1	68.3%	10%
	2	95.5%	20%
	3	99.7%	30%
20	1	68.3%	5%
	2	95.5%	10%
	3	99.7%	15%
30	1	68.3%	3.3%
	2	95.5%	6.7%
	3	99.7%	10.0%

For a system with $\epsilon \leq 0.1$ (10% accuracy or better) and confidence limits of 68.3% or better, $K/\epsilon \geq 10$; thus in Figure 7.1, the region above the $K/\epsilon = 10$ curve includes all acceptable values of $\bar{\phi}_s A$ for any signal-to-noise ratios. Figure 7.1 shows that $\bar{\phi}_s A \geq 37$ even with an infinite signal-to-noise ratio.

7.2.3 <u>Response Time</u>

By its very nature the ratemeter in a detector channel has a time constant τ. Changes in ϕ_s which occur in times appreciably less than τ seconds will not be "followed" by the ratemeter. It is necessary to determine τ so that resolving-time errors are less than the desired system error, ϵ. In particular, the time constant is selected so that

$$\frac{\tau}{\phi_a} \left[\frac{d\phi}{dt}\right]_{max} \leq \epsilon \qquad (11)$$

where $\left[d\phi/dt\right]_{max}$ is the maximum time rate of change of ϕ as the detector moves over a fallout pattern and ϕ_a is average of ϕ in the region of $\left[d\phi/dt\right]_{max}$. Equation (11) states that the fractional change in ϕ will not exceed ϵ in one time constant interval.

It will be noted that ϕ_a is the sum of signal and background. Since the background probably can be assumed to change only slowly when the signal is changing rapidly,

$$\left[\frac{d\phi}{dt}\right]_{max} = \left[\frac{d\phi_s}{dt}\right]_{max} .$$

Therefore, if τ is such as to satisfy (11) when there is no background, it also will satisfy (11) when there is background.

7.2.4 Overall Accuracy of Detector Channel

The signal-to-noise ratio generally will be worst when the signal itself is small. Thus, $\bar{\phi}_s A$ would be evaluated from equation (10) for the S obtaining for passage over the least isopleth to be resolved. On the other hand, when a traverse is made over the "heart" of a fallout pattern where the isopleths are closely spaced, the response time of the instrument will limit overall accuracy. Thus, the τ from equation (11) is to be inserted into equation (10) when $\bar{\phi}_s A$ is evaluated.

7.3 Signal and Noise

While it is not possible to calculate exactly the signal and background which will obtain after even a single bomb burst, the calculations may be done accurately enough to guide the design of a practical detector.

7.3.1 Expected Signal

The flux $\bar{\phi}_s(h)$ obtaining at an altitude h above contaminated ground has been calculated; the maximum time rate of change of $\bar{\phi}_s(h)$ has been calculated for an idealized fallout pattern. These data are given in Table 7.2; Figure 7.2 shows $\bar{\phi}_s(h)$ vs. h for a 1 R/hr level at the ground.

The radiation reaching the detector is concentrated mainly in the solid angle around the vertical below the detector; this

Table 7.2

GAMMA-RAY FLUX AT A DETECTOR AT ALTITUDE h ABOVE THE GROUND

Detector Altitude h, feet	Gamma-Ray Flux, $\overline{\phi}_s$, at Detector Above Ground Contamination Levels of					$[d\overline{\phi}_s/dt]_{max}$ for Speeds of	
	1 r/hr	10 r/hr	30 r/hr	100 r/hr	300 r/hr	340 kts	1000 kts
500	3.3×10^4	3.3×10^5	9.9×10^5	3.3×10^6	9.9×10^6	7.15×10^5	1.8×10^6
1000	8.0×10^3	8.0×10^4	2.4×10^5	8.0×10^5	2.4×10^6	1.73×10^5	4.4×10^5
4000	5.6	5.6×10^1	1.7×10^2	5.6×10^2	1.7×10^3	1.21×10^2	3.1×10^2
6000	3.0×10^{-2}	3.0×10^{-1}	9.0×10^{-1}	3.0	9.0	6.1×10^{-1}	1.8

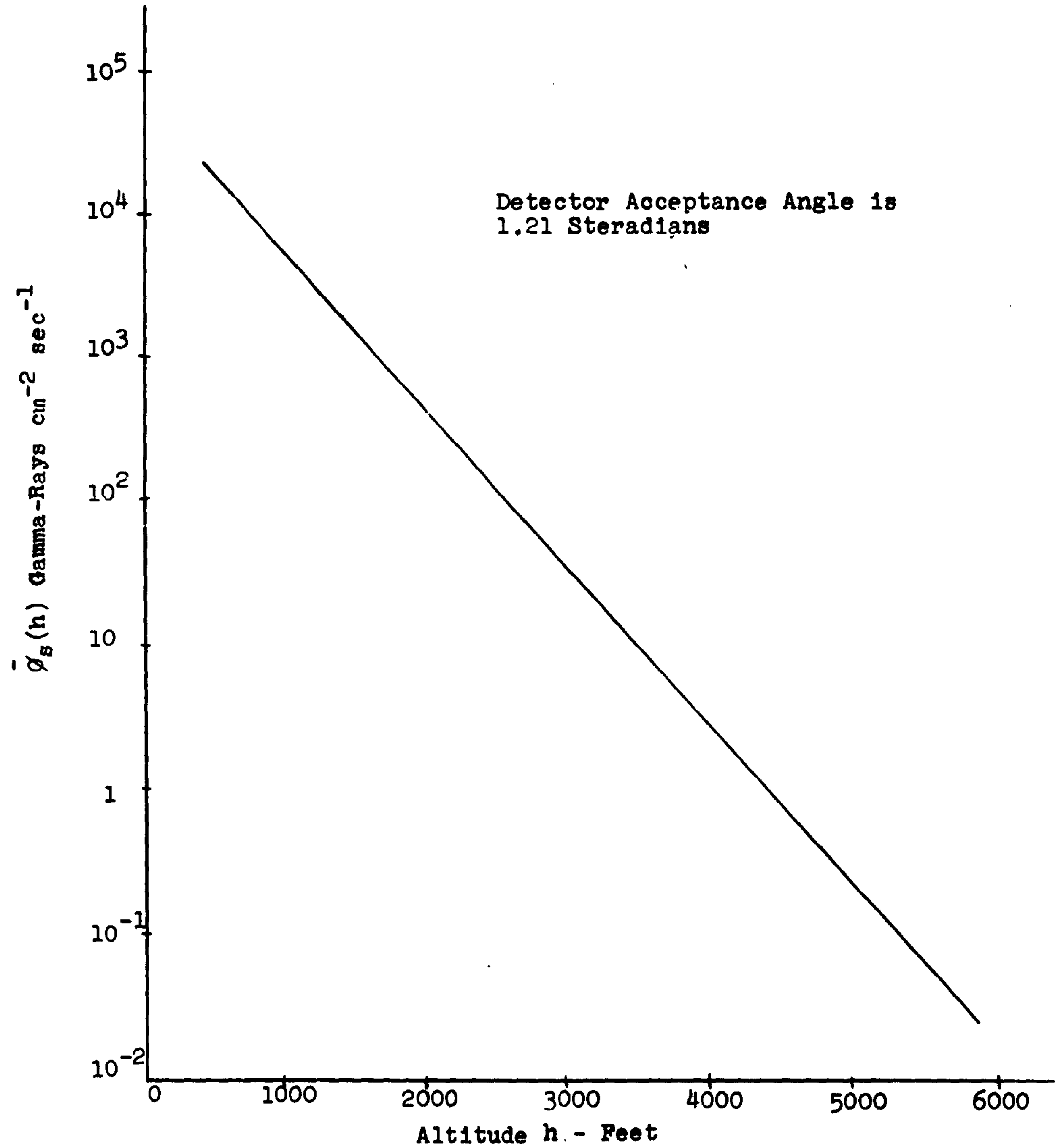

Fig. 7.2 Gamma-Ray Flux at Detection h Altitude Above Ground Radiation Level of 1 R/hr

may be seen from Figure 7.3, which shows the angular distribution of the radiation for an altitude of 1800 feet. This angular distribution is derived directly from Monte Carlo data generated at GD/FW for another project (Ref. 7.2). The angular distribution is only weakly dependent upon altitude for the range of altitudes of interest here. The data of Figure 7.3 may be taken to apply at the altitudes of interest here. See Appendix C for further discussion of the validity of this angular distribution.

Representative data of Figure 7.3 are given to aid in the choice of a detector acceptance angle. It is desirable to retain as much of the unscattered radiation as possible to keep the number of photons striking the crystal as large as possible and to maximize the ratio of photons entering in the (0^o+ x) acceptance half angle to the (180^o-x) acceptance half angle. This last item is of importance in the design of a detector to eliminate the effects of background (see Section 7.4.3).

Acceptance Half Angle	Scattered + Direct Normalized at 0-30°	Relative Amount of Photons Retained	Ratio $\frac{(0^o+x)}{(180^o-x)}$
0-24°	85	70	30.2
0-30°	100	82	27.6
0-45°	127	100	21.2
0-60°	144	100	16.2

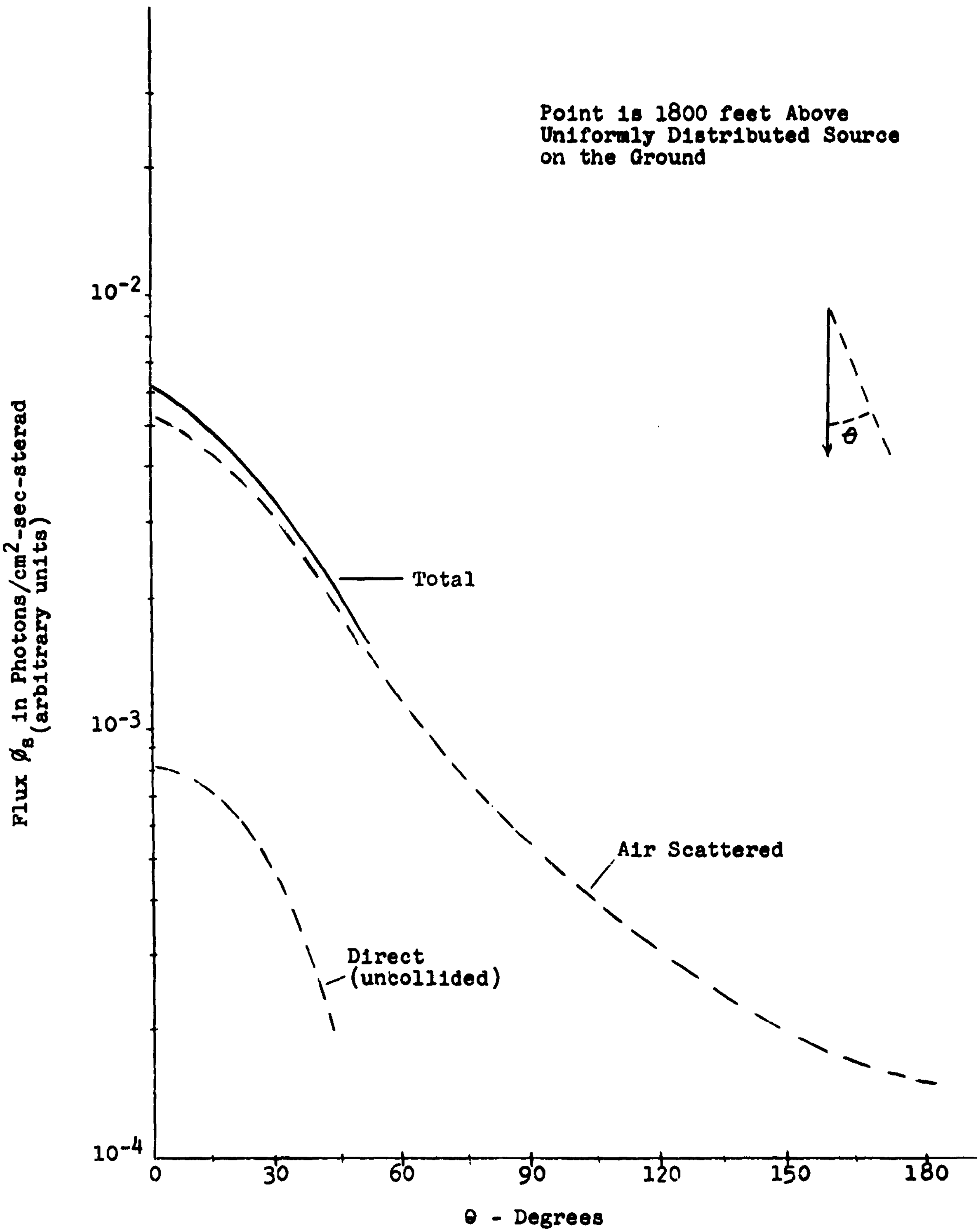

Fig. 7-3. Angular Distribution of γ-Radiation at a Point

The acceptance half angle of 45° appears to be a good choice in that the number of photons admitted is relatively large; all the direct beam is accepted and the $(0^\circ+x)/(180^\circ-x)$ ratio is large. Additionally, with a 45° acceptance half angle, approximately 60% of all the photons available to an isotropic detector are admitted. This 45° half angle will be used in all further calculations.

The intensity of radiation at the detector depends upon geometrical altitude and upon the mass thickness of the air between source and detector. The latter quantity is dependent on air temperature, barometric pressure, and to a small degree, relative humidity. Ordinarily, barometric pressure varies about the mean of 29.96 in. Hg by no more than 5%. Sea level air temperatures range from −30°C to +40°C depending upon season and location; thus air temperature variations of, say, ±12% are to be expected. The variation in air density due to these effects may be as great as ±17%.

The largest conceivable density of water vapor in the air (100% relative humidity at 40°C) is 5.0×10^{-5} gm/cm^3; this value corresponds to a mass increase of approximately 4% for the saturated air. Generally, the relative humidity is less than 100%; and saturation is especially unlikely in regions of the country where extremely high temperatures occurs. Thus, the effect of humidity will be ignored hereafter.

The variation in flux at the detector due to the above mentioned meteorological effects may be greater than ±20% if no compensation is made. If however, the survey aircraft maintains a constant density altitude (rather than constant true altitude) the error will be minimized; for altitudes of approximately 1,000 feet or more, the error will be within system accuracy (10%). Alternatively, of course, the necessary corrections may be made by the system analog computer.

7.3.2 Expected Noise (Background)

Background from three sources must be considered. Natural background is, or can be made negligible. Bomb debris remaining suspended in the air may be quite severe. Contamination of the survey aircraft also may be severe.

7.3.2.1 Background from the Air Burden. Typically, from a surface or low altitude burst about 60% of the total radioactivity appears as fallout within a period of, say, 12 hours subsequent to detonation. The remainder of the radioactivity stays suspended in the atmosphere for some time. Thus, in down wind areas where the short-term fallout is essentially complete, the air burden of radioactivity may be far from negligible.

It may be assumed that far down wind the residual radioactive cloud (that remaining about 12 hours) is reasonably homogeneous and "thick" in terms of altitude of the survey aircraft. Thus the airborne detector is, for all practical purposes, immersed in a uniform volume source of radiation. This volume source is bounded on one side by the ground which itself is a surface source of radiation.

While the detector and its collimator may be surrounded by a small volume of uncontaminated air, parts of the airborne source are very near the detector, so proximity alone may make the background quite large even when the specific activity of the air is small.

As would be expected, the flux reaching a downward-looking detector from the distributed air source depends upon the thickness of the layer of air beneath the detector, i.e., upon detector altitude. Figure 7.4 shows the dependence of the dose rate(rather than flux) at a 2π detector vs. air layer thickness, in terms of the dose rate which would obtain for an infinite air medium. It will be seen that a 1,000 foot thick air layer gives 90% of the infinite layer dose rate. Further, it will be seen that the dose rate, hence the flux, increases rather slowly with increasing altitude, and is essentially constant above 1,000 feet.

Figure 7.5 shows the specific activity of the air which will give a flux equal to that from the 1 R/hr isopleth at a detector with 1.21 steradian (a cone of 45° half angle) acceptance angle (see Section 7.3.1).

Twelve hours after the explosion of a single one MT bomb, the specific activity of the air (in the down wind region where fallout levels would still be of interest) is expected to be no more than approximately 0.12 $cm^{-3}sec^{-1}$. The specific activity of the ground will be about 7×10^{5} $cm^{-2}sec^{-1}$ per R/hr of contamination.

7.3.2.2 Background from Contamination of Aircraft. If the survey aircraft passes through contaminated air, its skin, and especially the leading edges of airfoils, will become

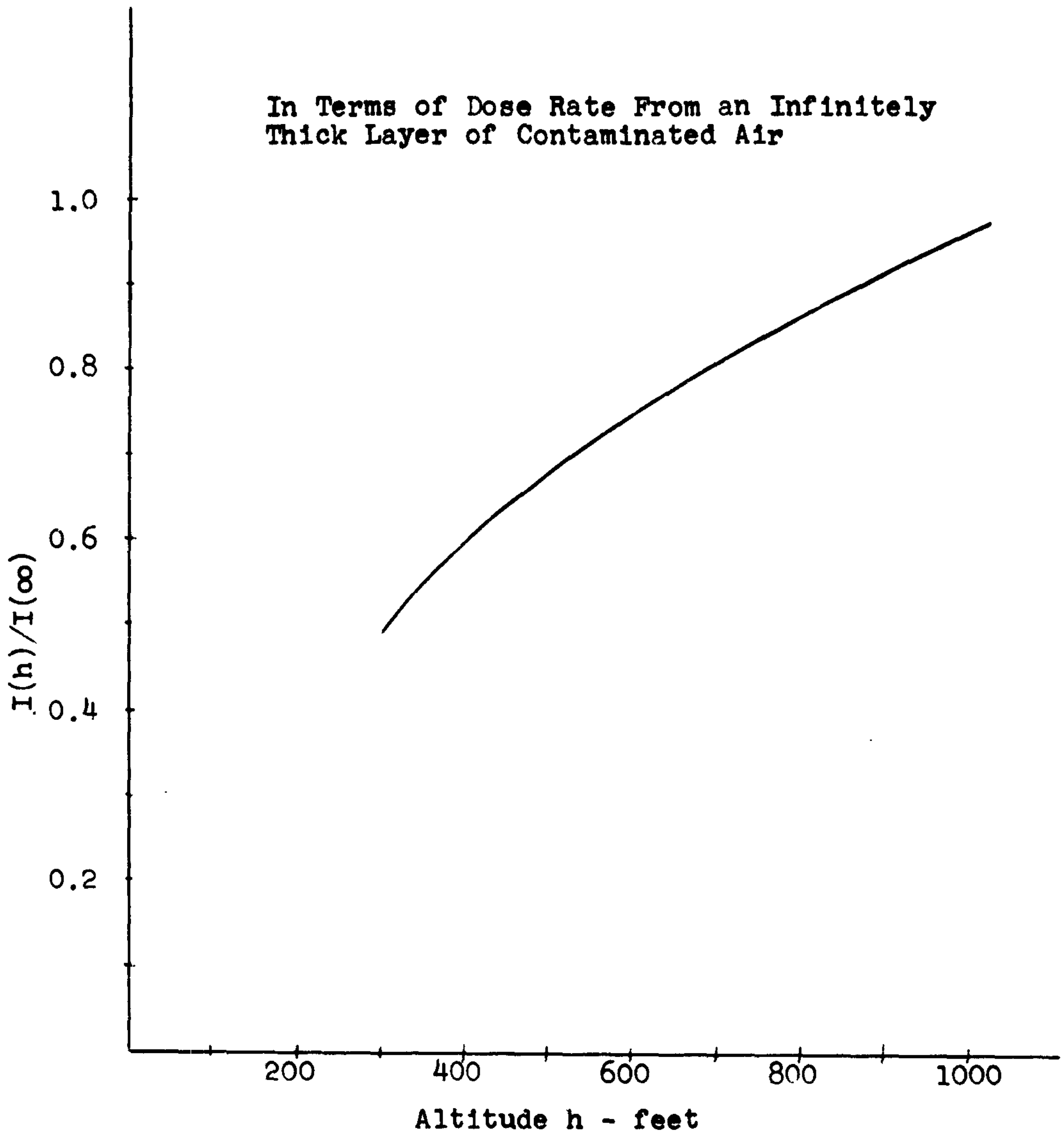

Fig. 7.4 Dose Rate I(h) at Altitude h

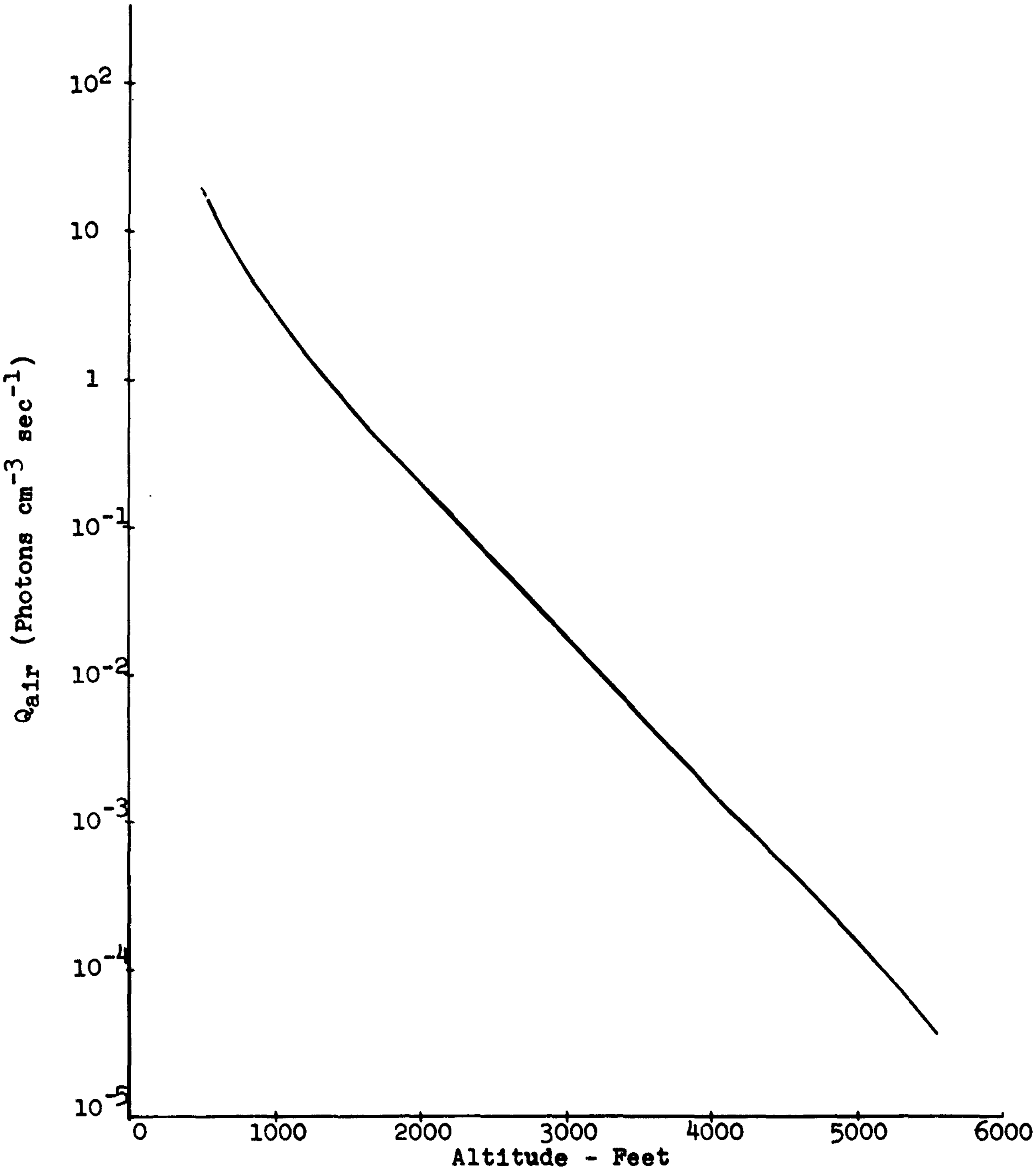

Fig. 7.5 Specific Activity of Air to Give Flux Equal to Flux from 1 R/hr Ground Level at 1.21 Steradian Detector

contaminated. It is not possible to calculate the extent of such contamination, but empirical data shows this may be in the R/hr region.

7.3.2.3 Natural Background. Natural background, mainly from cosmic radiation, is small at low altitudes, amounting to approximately 1.2 counts/cm^2 steradian.

7.4 Practical Design

For design purposes it is required that the detector channel indicate γ-ray flux with an accuracy of 10% or better with confidence limits of 68.3% or better. Operation is thus limited to values of $\bar{\phi}_s A$ and S which fall on or above the K/ϵ = 10 curve in Figure 7.1. The dynamic range of the detector channel is to be 1:1000, to enable measurements over fallout sources in the range 1 R/hr to 1000 R/hr (ground level). For the reasons given in Section 7.3.1, the half angle of the detector collimator is taken to be 45^o; the solid angle of acceptance is 1.21 steradian. With this angle of acceptance a detector will receive 60% of the total flux(s) listed in Table 7.2. The natural background will be approximately 1 sec^{-1} per cm^2 of sensitive area. Thus, the background will be approximately numerically equal to detector sensitive area.

7.4.1 Simple Case, Clean Air

If there is no air contamination, natural background will be the only source of "noise," and signal-to-noise ratios can be found from the data in Figure 7.2 and Table 7.1. A signal-to-noise ratio of 1.0 can be obtained at an altitude of 4400 feet over a 1 R/hr isopleth. From Figure 7.1, the minimum value of $\bar{\phi}_s A$ (average signal through the detector) is found to be 108 sec^{-1}. Since $\bar{\phi}_s$ is 1.0 cm^{-2} sec^{-1} in this case, A should be 108 cm^2. This is an awkwardly large detector whose use here is not feasible.

If a signal-to-noise ratio of 10 is available, $\bar{\phi}_s$ A is reduced to the more reasonable value of 43 sec^{-1}. From Figure 7.2, it is found that a 10:1 signal-to-noise ratio can be obtained 3500 feet above the 1 R/hr isopleth, and that $\bar{\phi}_s$ will be 10 $cm^{-2}sec^{-1}$. Thus, the detector area need be only 4.3 cm^2. With the stated dynamic range of 1:1000, the counting rate over the 1000 R/hr dose rate is 43,000 sec^{-1}, which is well within the capability of the detector channel.

7.4.2 Illustration of Effect of Air Contamination

A more realistic design is one which takes into account air contamination. Using the rather pessimistic estimate of air burden given in Section 7.3.2.1, and referring to Figure 7.5, it is found that a 1:1 signal-to-noise ratio obtains at 2200 feet above the 1 R/hr isopleth.

This is to say both air and ground sources will give fluxes of 280 $cm^{-2}sec^{-1}$ at the detector. Evidently natural background ($\approx$ 1 $cm^{-2}sec^{-1}$) is negligible when the air contamination is so great, so the signal-to-noise ratio is unity in this case.

From Figure 7.1, it is found that $\bar{\phi}_s A$ must be 108 sec^{-1}. The signal flux $\bar{\phi}_s$ is 280 $cm^{-2}sec^{-1}$, so the sensitive area of the detector has to be only 0.4 cm^2. With a dynamic range of 1:1000 the range of actual counting rates for this detector will be from 216 sec^{-1} at the 1 R/hr isopleth to 108 x 10^5 sec^{-1} at the 1000 R/hr isopleth.

In the absence of air contamination, this detector will show a background rate of ≈ 1 sec^{-1}. At 2200 feet, the signal-to-noise ratio will be better than 100:1, so $\bar{\phi}_s A \approx 37$. The signal flux at this altitude is 280 $cm^{-2}sec^{-1}$ above the 1 R/hr contour, so A actually need be no greater than 0.13 cm^2. Evidently, the 0.4 cm^2 detector is suitable for use at 2200 feet in clean or contaminated air.

The resolving time, τ = 1.4 sec, of the ratemeter was calculated from equation (11),

$$\tau \leq \epsilon \frac{\bar{\phi}_a}{\left[\frac{d\bar{\phi}}{dt}\right]_{max}}$$

where ϵ was set at .1 and values of $\bar{\phi}_a = 9.9 \times 10^6$ and $\left[\frac{d\bar{\phi}}{dt}\right]_{max} =$ 7.15×10^5 were chosen from Table 7.2 for speeds of 340 mi/hr, above the 300 R/hr isopleth and an altitude of 500 ft, the extreme case.

7.4.3 Background Detector

Now, as indicated earlier, it is necessary that the background be known when the signal-to-noise ratio is unfavorable. The background may be determined with a "noise" detector identical to the main detector, but looking upward. At an altitude of 1800 feet, the upward-looking noise detector will receive approximately 5% of the flux from the ground that the signal detector receives (see Figure 7.3). At 2200 feet the "noise" detector will receive only about 2% from the ground. This effect is about equal that of the natural background, and will be ignored hereinafter. The effect could be reduced further by use of a narrower acceptance angle (see Section 7.3.1).

7.4.4 Specific Design

A preliminary engineering design, based on the ideas of the immediately preceding sections, is given here. The detector and its lead housing are shown in Figure 7.6. The scintillator is a standard 1.75 inch-diameter, two inch-long NaI(T) crystal, preferably of the "matched-window" type. The photomultiplier tube is the 1-1/2-inch type 6199 or equivalent. To minimize the volume included within the shield, the preamplifier should be located just outside the shield. The dynode resistor chain is included in the detector assembly.

The shield is shaped to minimize its weight while providing a minimum lead thickness of 2-1/4-inch. This thickness of lead

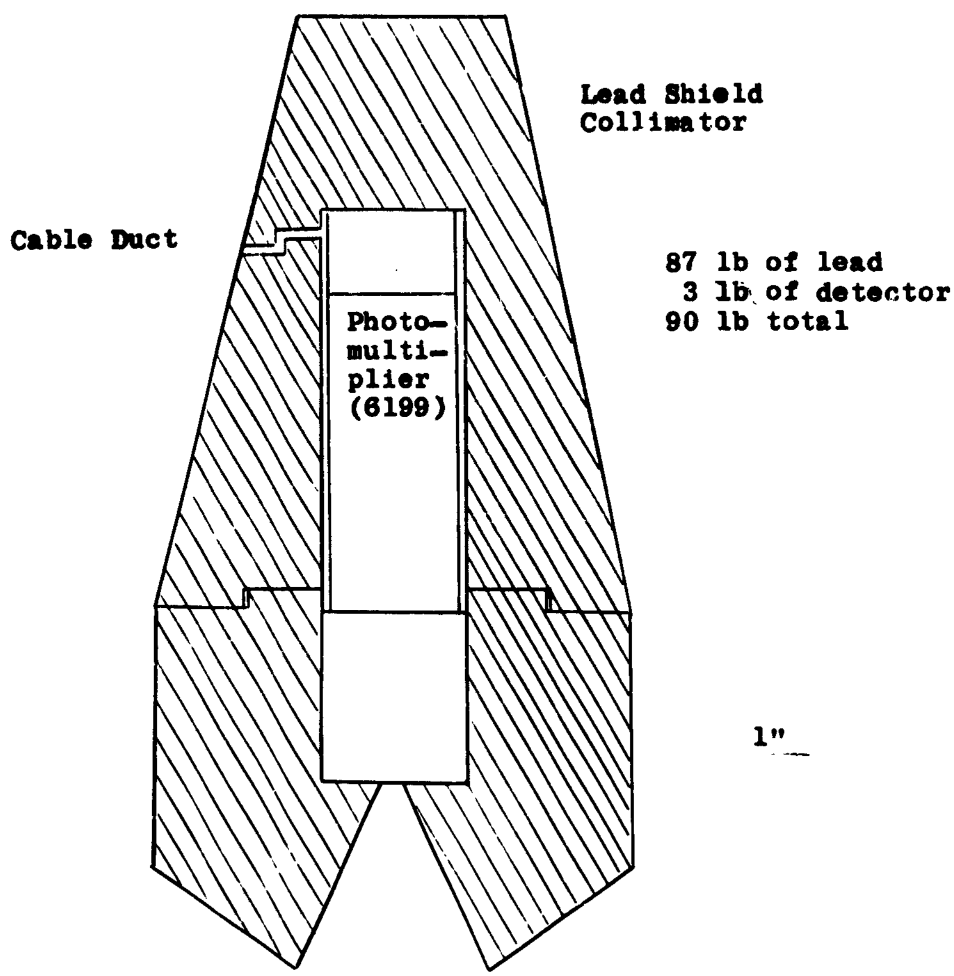

Fig. 7.6 Shield-Collimator for Detectors

is sufficient to reduce 1 Mev flux by a factor of more than 100. At the period 10-12 hours after a burst when a search is begun, the flux at the ground with energies above 1.0 Mev is about 10% of the total. Since photons of 1.0 Mev pass through about five relaxation lengths in reaching 2200 feet, it can be seen that all particles originally of energy less than this will be repeatedly scattered and considerably degraded in energy. Six of the 10% of the initial flux above 1.0 Mev is in the range 1.14-1.47 Mev where the 2200 feet altitude still represents about four relaxation lengths. So it can be safely assumed that the spectrum at altitude is much softer than on the ground and that very few photons of energy greater than 1 Mev exist. Consequently, the lead shield calculated on the basis of 1 Mev flux should be more than adequate. As shown, the sensitive area of the detector is 1.25 cm^2, three times the minimum useful area found in Section 7.4.2. Use of the larger area provides slightly improved sensitivity, and gives a reasonable safety factor to include effects of various approximations made earlier.

The acceptance angle of the collimator aperture in the shield is 1.21 steradians, the value determined previously. The weight of the shield and detector (excluding shield mounting hardware) is approximately 90 pounds and the total weight for a system which includes both "signal" and "noise" detectors will be approximately 200 pounds.

The signal-to-noise ratio may be improved by minimizing the quantity of contaminated air within the acceptance cone of the detector. Thus, as indicated in Figure 7.7, the first few feet of air below the detector may be isolated from contamination by placing the detector some distance from the skin of the fuselage (it is presumed that the air inside the plane will be uncontaminated).

This expedient is equivalent to removing a truncated conical volume of contaminated air (indicated by the dotted lines in Figure 7.7) from the acceptance cone of the detector. Approximate calculations indicate that a 25% to 50% reduction in background may be possible if the column of clean air can be made several feet long.

Evidently, the detector can be surrounded with clean air only if the skin of the aircraft provides a barrier to the external contaminated air. The skin, however, will itself become contaminated; it will then constitute a fixed source within the cone of acceptance of the detector.

To avoid this difficulty, it is suggested that the normal skin of the aircraft be replaced with a continuously renewable barrier. This may be done as shown in Figure 7.7 where (aluminum) foil covers the fuselage; as the foil beneath the detector becomes contaminated, it is advanced, bringing into place fresh uncontaminated foil.

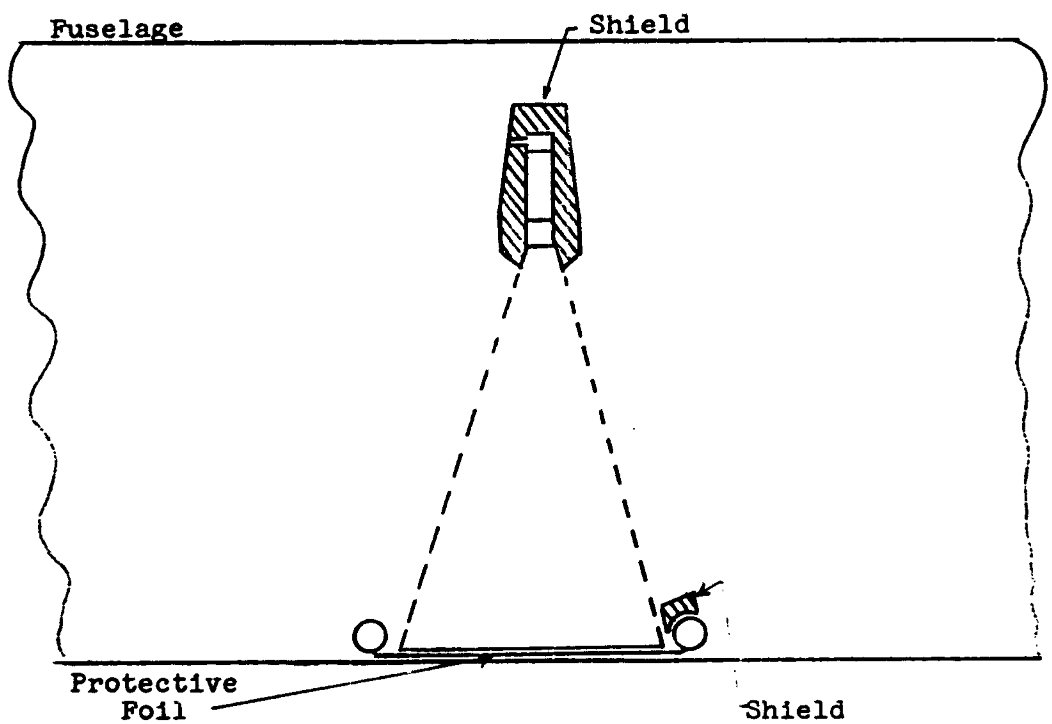

Fig. 7.7. Means for Minimizing Background from Contaminated Air

7.4.5 Detector Channel Electronics

A block diagram of the electronics for one detector channel is shown in Figure 7.8. The function of the preamplifier is to match the impedance of the signal cable leading to the main amplifier, so that the latter may be located in the operator's console at some distance from the detector proper. The amplifier raises the signal to a level convenient for further signal processing. The discriminator rejects small (electrical) noise pulses, and forms acceptable signal pulses to uniform size and shape.

The shaped pulses are fed into a ratemeter circuit which develops an analog output proportional to the pulse rate. The analog output is fed to a visual indicator and/or to the system computer.

At some point in the circuit ahead of the ratemeter, it is desirable to differentiate the signal pulses from the photomultiplier tube. The differentiating time constant should be approximately equal to the rise time of the pulses appearing at the photomultiplier anode, i.e., about 0.25 µsec. This expedient maximizes the counting rate which the channel can tolerate without "pile-up."

High voltage (1000–2000 VDC) for the photomultiplier is derived from a well-regulated power supply. The resistance of the dynode chain must be relatively small in this application, in order to maintain reasonably constant photomultiplier gain over a wide range of counting rates. The current capacity of

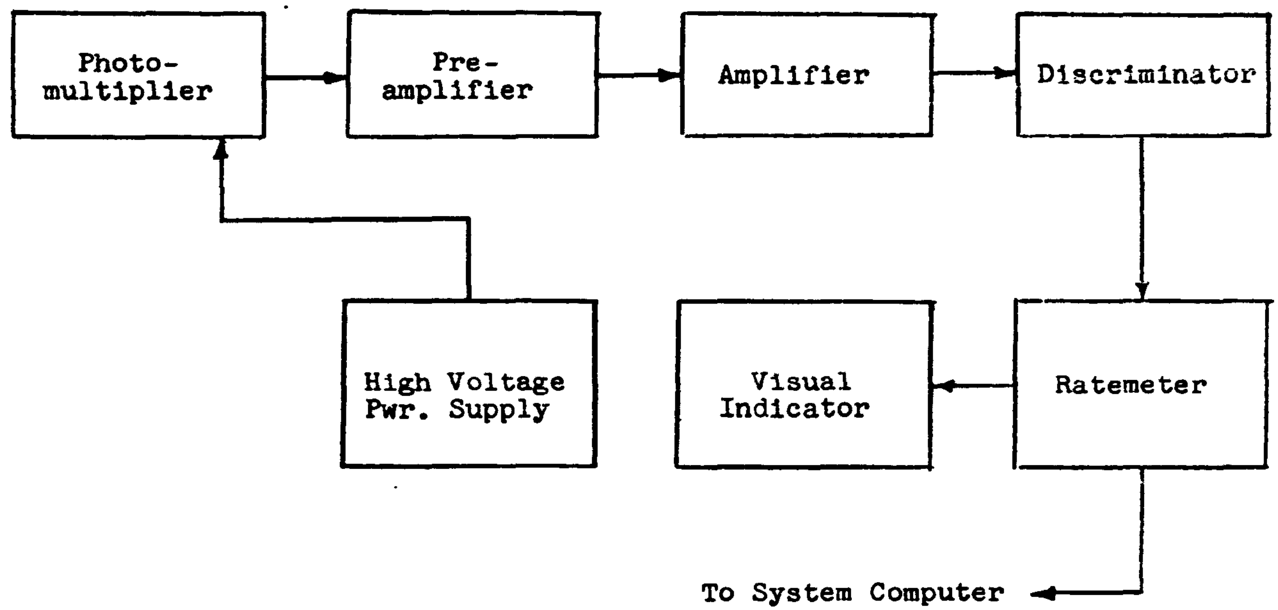

Fig. 7.8. Block Diagram of Detector Channel

the power supply will be somewhat greater than that usually needed for photomultiplier operation.

All of the electronic components in the detector channel are readily available commercially in vacuum tube models. The vacuum tube equipments, however, are inconveniently large and heavy, and often too fragile, for the intended application. Transistorized equipment is far superior for the present purpose. Much, if not all, of the necessary equipment is available commercially (see Appendix A). If commercial equipment is not fully suitable for this application, transistorized equipment may be fabricated as required according to existing "standard" designs.

Some idea of the size of the detector channel electronics can be gained from Figure 7.9, where is shown a package containig a high voltage power supply, all of the electronics indicated in Figure 7.8, and a number of additional electronic functions. This package was built by General Dynamics/Fort Worth for the ARENTS satellite. The package occupies 200 cubic inches, and weighs four pounds.

While all the electronics for both "signal" and "noise" detectors can be gotten into one such package, it probably is most desirable to use one package for each detector channel. Then failure of one channel would not affect the other in any way; and maintenance and repair is reduced to a "plug-in" operation.

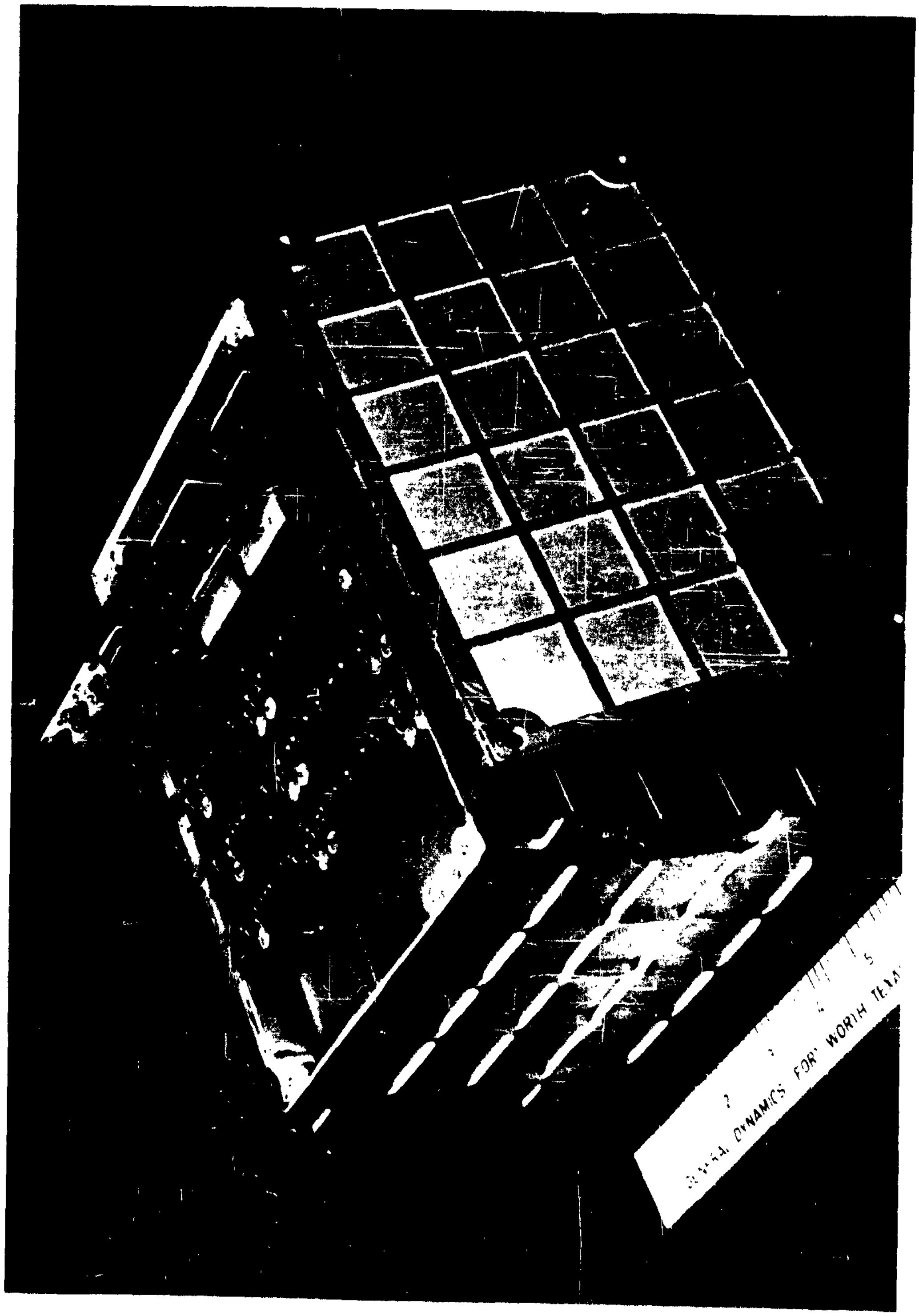

Fig. 7.9 Electronic Package for ARENTS

7.5 Calibration and Standardization

By "calibration" is meant the empirical determination of the relation between ground-source strength and detector output. By "standardization" is meant the adjustment of a detector channel to the proper sensitivity.

7.5.1 Calibration

Since it is hardly feasible to calibrate against a real fallout pattern, a calibration procedure using artificial sources is required.

Consider a detector at altitude h above uniformly contaminated ground having a specific activity of S_o γ-rays $sec^{-1}cm^{-2}$. With the geometry of Figure 7.10, the strength of an elemental ring source is

$$dS_o = 2\pi\ S_o\ a\ da;$$

the flux at the detector from dS_o is

$$d\phi_o = \frac{2\pi S_o B e^{-\Sigma(a^2 + h^2)^{1/2}}}{4\pi\ (a^2 + h^2)}\ a\ da \qquad (12)$$

where B is a buildup factor and Σ is the macroscopic cross section for γ-rays in air.

Now consider a point source on the ground at distance a from the subdetector point (Fig. 7.11); let the strength of this source

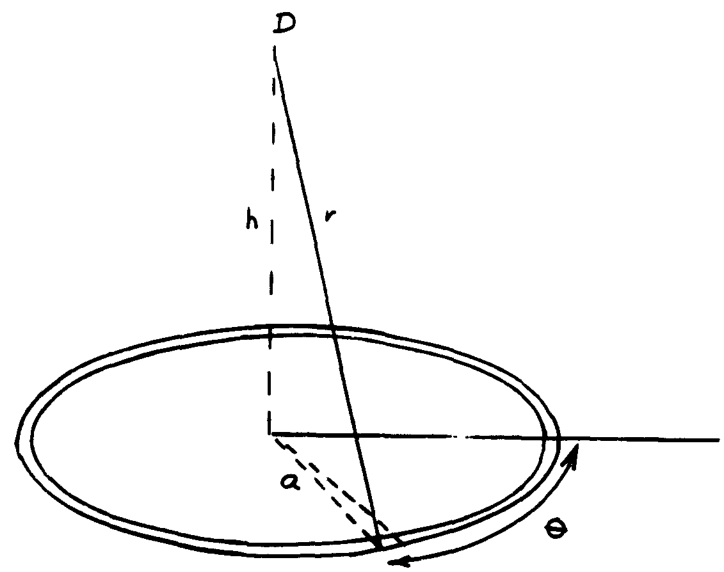

Fig. 7.10 Geometry for Distributed Source

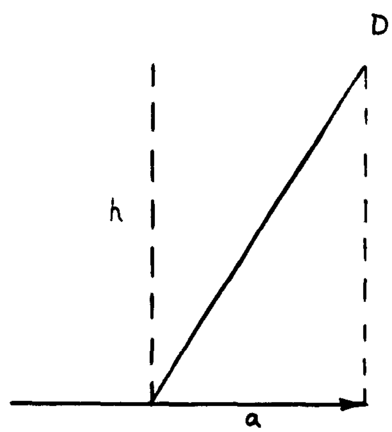

Fig. 7.11 Geometry for Calibration

be equal to the specific activity of the ground source S_o, mentioned above. The flux at the detector from the point source is

$$\phi_p(a) = \frac{S_o B e^{-\Sigma(a^2 + h^2)^{1/2}}}{4\pi\ (a^2 + h^2)} \qquad (13)$$

which differs from (12) only by the factor $2\pi a da$.

Combining (12) and (13), obtain

$$d\phi_o = 2\pi\ \phi_p(a) a\ da \qquad (14)$$

Once $\phi_p(a)$ is determined experimentally, ϕ_o is found at once by numerical integration of (14):

$$\phi_o = 2\pi \sum_{i=1}^{\infty} \phi_p(a_i) a_i\ \Delta a_i .$$

The point source flux $\phi_p(a)$ may be measured by recording counting rate as a function of time (i.e., position) as the detector moves at constant velocity along a straight line passing directly over the source.

The error due to detector motion with respect to a distributed source is discussed in Section 2.3; there it is shown the magnitude of this error is proportional to τ , the resolving time of the system. When a detector is in motion with respect to a point source, equation (11) is still valid, but $[d\phi dt]_{max}$ is no longer a property of the source, but is determined by the velocity of the detector. In this case, the fractional error due to detector motion is related to $\mathcal{T}$ by

$$\epsilon \approx \mathcal{T} v/h$$

The resolving time, $\mathcal{T}$, will be of the order of 1 sec for a practical system, so

$$\epsilon \approx v/h$$

or at an altitude of 1000 feet,

$$\epsilon \approx 10^{-3} v.$$

Since ϵ should be made as small as possible for calibration purposes, v has to be quite small. For $\epsilon \approx 0.01$, v must be less than 10 ft/sec; a speed which is hardly within the range of winged aircraft. For this reason it is recommended that calibration be done with the detector in a helicopter.

An adequate calibration can be obtained with a Co^{60} source; the average γ-ray energy for Co^{60} is 1.25 which does not differ greatly from the $\approx$1 Mev effective energy of γ-rays from fallout. If greater spectral similarity is desired, a composite calibration source may be used (e.g., $Co^{60} + Cs^{137}$).

The maximum fractional error resulting from the motion of the detector is approximately v/hr, v being the detector velocity. With small v, this error can be made negligible, so the controlling error will be that associated with counting statistics.

With a reasonably slow traverse (v $\approx$ 10 ft/sec) the calibration source should have a strength of several hundred curies, the exact value depending upon details of the calibration procedure.

The traverse of the source can be made by a helicopter flying at reduced speed and guided by radar and/or a conspicuous grid marked on the ground. Another practical means of obtaining the same information would be to place the detector at the top of a 1000 foot tower (e.g., the tower at NRTS) and move the source along the ground beneath it.

Perhaps the best calibration source would be a reactor fuel element of an age and history to give a γ-ray spectrum like that of fallout of some specified age. However, handling and licensing problems probably preclude their use.

7.5.2 Standardization

Having calibrated one system against a standard source, the calibration may be transferred to other systems by use of standard sources to provide a known signal at the detector. A practical method for standardization is to use a small radioactive source to produce a known flux at the detector; the ratemeter is then adjusted so that it properly indicates the known count rate so obtained. It would be desirable to add a remotely-operated source to the shield assembly shown in Figure 7.6, so that in-flight standardization can be done simply and at will.

References

Ref. 1 R. D. Evans, "The Atomic Nucleus," McGraw-Hill Book Company, New York, 1955, (U)

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Ref. 3 S. Glasstone, "The Effects of Nuclear Weapons," United States Atomic Energy Commission, April 1962. (U)

8. DATA SYSTEM STUDY

The purpose of this section is to study the data system that might be assembled from commercially available components. The term, data system, refers to the entire data link from the radiation detector in the low flying survey aircraft to the data display device in the national center. Obviously, such a data system can have many variations. In order to present the variations studied without repetitious descriptions, the systems, subsystems, and components of the subsystems are described; then the various airborne data systems and the ground data systems are described.

The major conclusion of the study is that the Flock Data System with facsimile data transmission to the CD Regional Headquarters is the preferred system. The Flock Data System consists basically of a radio altimeter, an inertial guidance system, dual radiation detectors, a computer for time-altitude corrections, a visual strip recorder data display, a facsimile data transmitter, and a long range radio.

8.1 Design Requirements

The designs of the proposed data systems are based on the following requirements:

(1) The data system must be operable in time of peace and must be capable of accomplishing its mission in time of war.

(2) The system must be operable in 150 to 350-mile an hour aircraft.

(3) The system must be capable of monitoring the multiple bursts of a saturation attack.

(4) The system must be capable of determining the radiation levels on the ground from measurements in the air.

(5) The system must be capable of operation in radioactive air burden that remains 12 hours after the initial fallout.

(6) The data must be presented in a timely, easily interpreted form.

8.2 System Description

8.2.1 Covey System

The Covey System consists of a mother airplane flying at approximately 20,000 feet altitude with several sensor carrying aircraft called "chicks" flying at low altitude, hence the name "Covey." The Covey System uses line-of-sight communication between the sensor carrying aircraft and the control aircraft. The control aircraft utilizes long range radio to relay the data to the OCD Regional Headquarters. The number of sensor carrying aircraft per control aircraft are determined by the type survey pattern to be flown.

The sensor carrying aircraft serves as a data measuring unit. It measures five parameters: (1) altitude, (2) dose rate, (3) latitude, (4) longitude, and (5) time. The dose rate is corrected for the effect of altitude and is referenced to a common time. The processed data are relayed to the control aircraft by telemetering.

The control aircraft serves as a data processing center, a communication center, and a flight control center. The data are received from all the sensor-carrying aircraft via telemetry. The data are processed into a format compatible with the data transmission system. The composite data are transmitted to the ground station by facsimile, teletype, or digital encoder, via long range radio.

Some of the merits of the Covey System are as follows:

(1) The system will have good reliability because of the many emergency methods that can be adopted. For example:

 (a) In case of telemetry failure, the sensor carrying aircraft can transmit descriptive numerical data on UHF or VHF radio.

 (b) In event of complete communication failure, the sensor carrying aircraft can record written data.

 (c) In case the long range radio fails, the data can be evaluated after flight because the data are recorded on magnetic tape and visual records.

(2) The system provides good in-flight coordination, because the data plotters in the control aircraft are also flight directors.

(3) The multiple data inputs from the sensor carrying aircraft give the data plotters sufficient data from which to plot the isopleths of the fallout.

(4) The system reduces the amount of air-to-ground communications as compared to the Flock System.

(5) The system is capable of operating with faster search aircraft.

The disadvantages of the Covey System are:

(1) The system requires a control aircraft which is expensive and complex.

(2) The system provides more aircraft and equipment than is needed for single burst requirements.

(3) The system is dependent on the control aircraft.

8.2.2 Flock System

The Flock System consists of a "Flock" of independent, sensor carrying aircraft flying at low altitude. Each Flock aircraft has a data collecting, data processing, and data transmission system.

The data system in the Flock aircraft is similar to that of the chicks in the Covey System except that the telemetry link is eliminated. The same parameters - - altitude, R/hr, latitude, longitude, and time - - are measured and processed as in the chick aircraft. The use of aircraft with a large payload capacity permits the Flock aircraft to utilize the same air-to-ground data transmission techniques as the Covey System.

The advantages of the Flock System are as follows:

(1) The data links between the chick and mother are eliminated.

(2) The expensive and complex mother aircraft is eliminated.

(3) The Flock aircraft can operate independently or dependently.

(4) The search patterns are flexible and can be easily redirected.

(5) The data are recorded on permanent records for postflight transmission in event of communication failure.

The disadvantages of the Flock System are as follows:

(1) The system does not offer good in-flight coordination.

(2) Each Flock aircraft must communicate with the ground station.

(3) The plotting of data will be difficult in rough air.

8.3 Subsystem Description

Several variations of the Covey System and the Flock System are possible. The following subsystems are presented in detail so that the discussion of the variations may be presented in block diagram without repetitious details.

8.3.1 Data Communications

The Covey System requires data transmission from the chicks to the mother aircraft. To hold down radio interference, it is desirable that line-of-sight communications be used between the chicks and the mother aircraft. Telemetry is a line-of-sight data transmission link which has been in use for many years.

The transmission of data from the mother aircraft in the Covey System or the chick aircraft in the Flock System to the ground stations requires long range radio. The CD Regional Headquarters have been selected as the data receiving stations.

8.3.1.1 FM/FM Telemetry. Frequency modulation/frequency modulation (FM/FM) telemetry has been used in flight testing aircraft and missiles for a number of years. The technique consists of frequency modulating a transmitter output with the outputs of subcarrier oscillators which have been frequency modulated by data signals. The frequencies of the subcarrier oscillators conform to the standards of the IRIG (Inter-Range Instrumentation Group) Steering Committee, which represents most military missile test ranges in matters pertaining to instrumentation.

The data to be transmitted from the sensor carrying aircraft (in this case latitude, longitude, and R/hr) are converted to electrical signals which provide a source of modulation energy for the subcarrier oscillators. The frequency modulated outputs of all subcarrier oscillators are multiplexed and amplified, thus providing a source of modulation energy which is used to frequency modulate the transmitter. This double modulation process results in an FM/FM output of the transmitter which is amplified and transmitted to the telemetry receiving aircraft.

In the control aircraft the telemetry signals from all the chicks are received on one multipurpose antenna. The output of the antenna is routed to a multicoupler which separates the telemetry signals and routes them to the correct receiver. The RF transmitted signals are demodulated by the receiver to reproduce the multiplexed signal transmitted by the sensor aircraft. The multiplexed signals are then routed to the signal discriminators where the subcarrier signals are separated and the original data signals that were transmitted by the sensor carrying aircraft are recovered.

The telemetry subsystem can be made up from the following components.

o FM/FM Telemetering Transmitter - FM/FM transmitters are available from several manufacturers. A typical unit is made by Tele-Dynamics, Division of American Bosch Arma Corporation. The unit is a compact 215 to 260 megacycle telemetry transmitter occupying only 20 cubic inches and weighing only 20 ounces. It employs reliable silicon transistors for high efficiency and offers true frequency modulation with better than 0.01% frequency stability.

o RF Power Amplifier - An RF power amplifier made by the same company as the transmitter provides 15 watts output into the antenna over the entire 215 to 260 megacycle telemetry band at modest DC and RF inputs. The unit occupies 23 cubic inches and weighs only 14 ounces.

o Wideband Amplifier - The same company makes a transistorized wideband amplifier in a compact unit for multipurpose use in telemetry transmitting systems to increase the output level at the multiplexed signal outputs. The amplifier is simple, rugged, and offers high stability in severe environments.

o Signal Multiplexer - A special multiplexer is recommended as most units available are designed for the full 18 IRIG subcarrier oscillators. The design of the multiplexer is simple — consisting of 100 K-ohm resistors in parallel with a 300 K-ohm resistor to ground. In the final design, the multiplexer can be built into the subcarrier oscillator tray.

o Subcarrier Oscillator - Subcarriers are manufactured by several companies and consist of several types. The voltage controlled oscillator (VCO) is the most commonly used because of its excellent stability, accuracy, and ease of calibration.

A typical subcarrier oscillator is made by Tele-Dynamics. It is a completely transistorized unit, offering high input impedance, exceptional linearity, and low current drain. The unit is insensitive to power supply variations, and has a filtered output.

o Multicoupler - A multicoupler is required to permit the control aircraft to have just one telemetry receiving antenna instead of one for each chick. Each chick will be transmitting continuously on different frequencies. The control aircraft must be able to receive all the transmissions simultaneously and then separate them. A typical telemetry multicoupler is made by Defense Electronics, Inc. The unit provides coupling between eight receivers and one antenna in the frequency range of 225 to 260 megacycles while providing 60 db minimum isolation between outputs.

o Preamplifier - The use of a multicoupler normally results in the attenuation of the received signal. A preamplifier is used to correct for the signal loss. The Defense Electronics, Inc., makes a unit that provides 20 db gain while operating into a 50 ohm system.

o Subcarrier Discriminator - In a telemetric data receiving system, a discriminator is required to separate the modulated composite subcarrier signals into the individual subcarrier signals. The discriminator band-pass filter passes only the subcarrier signal to which it is tuned. Commercially available discriminators such as those made by Tele-Dynamics are available with better than

0.1 percent linearity and 0.5 percent stability over a 24 hour period.

8.3.1.2 Long Range Radio. The use of ionospherical bounce to accomplish long range radio communications has been in use for a number of years. Present ionospherical telegraphic and voice communications use the band from about 4 to 28 mc (megacycles). During periods of lower sunspot activity, the upper frequency may have to be lowered to 20 mc. The airborne radioactivity 12 hours after the last burst will not present a serious radio communication problem due to the many frequencies available and the eight CD regional receiving stations.

The use of single side band (SSB) high frequency (HF) radio provides a four-to-one power advantage over amplitude modulation (AM) where the power is divided between the carrier and the two side bands. The airborne SSB HF radio is capable of producing 400 kw PEP (peak envelope power) permitting data transmission 2,000 to 3,000 miles. The interface components required to make the data compatible with the long range radio are described in following paragraphs.

The data rate is determined by the bandwidth of the single side band. Digital data can be handled at 75 bits per second. Teletypewriter data can be handled at 100 words per minute. Facsimile data depends on the design of the particular facsimile transmitter. A typical facsimile transmitter can send an 8 x 10 map in six minutes.

Several companies manufacture long range single side band (SSB) high frequency (HF) radios. The Collins Radio Corporation makes the 618-T which provides 28,000 channels with 1 kilocycle spacing. The set weighs only 50 pounds and is designed for airborne use. The set receives and transmits on 2 to 30 megacycles. It has 400 watts outpower power. The long range radio requires interface equipment to match it with the type equipment working into it. A description of some available interface equipment is as follows:

o TE-204A-2 Collins Synchronous FSK Data Modem - The data modem is used primarily in air-to-ground communication networks. The modem transmits and receives synchronous, serial, binary data over a standard 3 kc (kilocycle) voice channel derived on SSB (single side band).

Transmitting at 75 bits per second, equivalent to 100 words per minute, the TE-204A-2 is particularly well suited for teletypewriter and many other applications. The TE-204A-2 synchronizes on the transmitted signal, not on the content of the message. Either the built-in or an externally supplied clock pulse can be used for synchronization. The unit uses frequency shift keying to convert binary data into four audio tones spaced 440 cycles apart in the frequency of 935 to 2255 cps (cycles per second).

For in-band frequency diversity and for time diversity operation, the modem transmits each binary bit on two tones, the first half of the bit at the low end of the band, the second half at the high end of the band.

o TE-399R-1 Teletype Adapter - In the transmit function, the unit accepts single channel, serial, nonsynchronous, Boudot coded data from a keyboard, tape reader, or storage unit. It also synchronizes accepted data for subsequent transmission.

o CV-786 - Single Channel Telegraph Terminal - The interface equipment provides a single channel of half duplex telegraph communication via single side band radio circuit. Teletypewriter rates up to 100 words per minute can be obtained for airborne applications.

The CV 786 operation allows for r-f frequency translation errors and in airborne applications can accommodate a Doppler shift for speeds up to 600 knots.

The CV 786 can be used in place of the TE-399R-1 and the TE-204A-2.

o Westrex Transmitting Converter - The output of the Westrex Facsimile Set AN/GXC-5 is 500 to 5000 cps (cycles per second) which exceeds the 3000 cps bandwidth of the SSB (single side band) radio. The transmitting converter converts the 500 to 5000 cps AM (amplitude modulated) signal to 1500 to 2300 cps FM (frequency modulated) signal.

8.3.2 Airborne Data Processing Systems

Three data processing systems were studied for the Covey System and the Flock System: (1) digital, (2) facsimile, and (3) teletype.

8.3.2.1 Digital Data. The Covey Digital System requires transmission of the data from the sensor carrying aircraft to the control aircraft. The most accurate way to transmit the geographical coordinates is in digital or decimal format. The position fixing system will either provide the geographical coordinates in digital form or the geographical coordinates may be converted by shaft encoders to the desired form. The rate of conversion must not exceed the response of the subcarrier oscillators used with the telemetry transmitter. The corrected dose rate data may be transmitted in analog form. In the control aircraft, all data are recorded on magnetic tape and displayed on a visual strip recorder. The data plotter will monitor the visual recorder to see that the data appears to be correct. The rate of data transmission to ground is limited to the frequency response (75 bits per second) of the single side band radio. A programmer, multiplexer, and encoder unit will convert the analog data in correct sequence and command the control gates of the shift registers so that the data will be put into correct format. During the time the analog signal is connected to the encoder, the encoder is driven through a complete cycle, to generate the N information bits which describe the analog signal level. The information bits are combined with the proper markers into the correct pattern for transmission.

The rate at which data will be received from each sensor carrying aircraft at the computer will vary with the number of sensor carrying aircraft per control aircraft as this will set the sampling rate. The 75 bits per second transmission rate will be used for the information from one airplane. If the system provides too much data, the sampling rate may be decreased or a threshold computer may be added to the data system of each sensor carrying aircraft. The threshold computer would transmit data only at discrete levels such as 1, 3, 10, 30, 100, 300, 1000 or 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024 R/hr. The use of a threshold computer requires that the data plotter determine the "hot line" information. It would also be desirable to use a magnetic tape recorder with each sensor aircraft to record the data before it was limited by the threshold computer.

The digital system for the Flock aircraft is similar to that of the Covey System except all equipment is in the Flock aircraft. The digital data from the navigation system are fed into a shift register. The analog data are converted to digital data by an encoder. The data are put into serial form and combined with the proper markers prior to transmission. The amount of data to be transmitted may be reduced by a threshold computer as was suggested for the Covey System. A magnetic tape recorder would be required for each Flock aircraft.

The transmission of digital data by long range radio to a ground station requires the use of a data modem such as a Collins Radio TE-204A-2 for interface equipment. A frequency shift keying (FSK) technique is used. Each binary bit is transmitted on two tones, the first half at the low end of the band and the second half at the high end of the band. In the receiver, the diversity combiner linearly combines the two halves of each bit, either of which is sufficient to distinguish the binary information. The digital system could be made up from the following components:

o Encoder - An encoder is a device which converts analog data to digital data or to binary-coded-decimal (BCD). Encoders are readily available which are capable of encoding to an accuracy of 10 or more binary digits, providing an inherent accuracy of better than 0.1 percent. A typical airborne unit is made by Dynamic System Electronic Corporation. The unit, designed to handle three analog inputs, meets MIL-E-S272C standards.

o Multiplexer - A multiplexer is a device which accepts the analog inputs and on command of a timing programmer presents each analog signal to the encoder for digitalizing. The multiplexer system is composed of a switch with bipolar capabilities and extremely high isolation from both ground and the driving source. A typical multiplexer made by Dynamic System Electronic Corporation incorporates both the encoder and multiplexer into one unit.

o Programmer - The programmer is the heart of the digital system. It contains a clock rate oscillator operating at the bit rate or some multiple thereof. A typical programmer is made by the Systron-Donner Corporation.

o Shift Register - The magnetic shift-register element is a passive solid state device which stores (remembers) binary information that has been fed into its input circuit, and reproduces that information by making available essentially the same binary information as its output terminals. The binary input information is introduced in the form of a current pulse driven into an input winding on a magnetic core, and the output information appears as a voltage pulse induced in an output winding on that core. A typical shift register is made by Magnetics Research Company.

o Synchronous Generator - The purpose of the synchronous generator is to accept randomly-timed, arbitrarily-shaped input pulses and to convert them into properly timed and shaped pulses compatible with standard wave forms. A typical unit is made by Computer Control Company, Inc.

8.3.2.2 Facsimile Data. The transmission of data from the mother aircraft of the Covey System or the chick of the Flock System can be accomplished by a facsimile transmitter. The facsimile transmitter transmits the map as amplitude modulated signal. The modulation characteristic is such that the maximum level occurs when scanning black and minimum level when scanning white. The amplitude modulated signal may be transmitted directly for one type of facsimile transmitter which operates at 180 rpm drum speed. Another type transmitter uses a converter to convert the amplitude modulated signal to a frequency modulated signal which is compatible with the SSB radio. Still another transmitter converts the amplitude modulated signal to digital data at 75 bits per second.

The facsimile map may be a complete plot of fallout or just plotted data points depending on the type survey made.

o A typical facsimile transmitter is made by Westrex Corporation. The transmitter is a portable field unit designed for the Marine Corps. It transmits an 8 x 10 inch map in six minutes over standard military AM radio transmitters. A signal converter or interface is made by the same company for converting the AM signal to FM for long range radio compatibility.

8.3.2.3 Teletype Data. The teletype consists of a manually operated teletype or a tape operated teletype, a teletype interface, and the long range radio. The teletype transmitter, when operated by tape, can handle 100 words per minute where each word contains four characters. Considering that latitude, longitude, and dose rate can be described in 12 characters, the teletype can transmit 33 data points per minute.

In using this system, the data plotter will plot the data on an area map to check for validity. He will then transfer the data to teleprinter tape by typing the numerical values with a teletype perforator. The completed tape is then used to operate the teletype transmitter.

o The teletype equipment may be purchased or leased. A typical teletype is made by Western Electric Co., Inc.

8.3.3 Position Fixing

Three techniques were studied to determine the geographical coordinates of the point over which the dose rate is measured. The systems can not rely upon ground navigation aids because such aids might not be available after an atomic attack.

8.3.3.1 Inertial Guidance System. The inertial guidance system consists of a stable platform on which a primary sensing device such as an accelerometer is used to detect any movement of the aircraft along a single axis. Such movement is known as translation. The force of gravity exerts an influence on an accelerometer. This force cannot be distinguished from a force exerted upon the mass due to accelerating motion. The method used to eliminate this error is to keep the accelerometer axis normal to the direction of gravity. This is done by mounting the accelerometers on a platform, or stable table, which is free from the attitude deviations of the aircraft. The most common method of stabilizing the stable table is by the use of gyros to detect any movement of the table from the vertical.

The Litton LN-3 Inertial Guidance System is in Air Force inventory and is used in operational aircraft such as the F-110. The system can provide one to three-mile accuracy during four to five hours flight time. A Bendix AN/ASN-39 computer is used with the system to give position indication, initial conditions, and a means for manually updating the position data. In the F-110 aircraft, this computer provides a backup navigation capability, in the event of a platform failure, by using air-speed and magnetic heading inputs.

8.3.3.2 Doppler-Attitude Navigation System. The Doppler-Attitude System utilizes Doppler radar to measure the velocity of the movement of the aircraft along three axes. The radar transmits three beams to the ground, then the Doppler effect is measured on each beam to determine the velocity. The computer takes the sums and differences to compute the aircraft velocity along the three axes. This system weighs more than the inertial system and offers less accuracy, but is less expensive.

The Doppler-Attitude System studied consists of an AN/APN-102 GPL Doppler, a Lear SL-200 altitude and heading reference, and a Bendix AN/ASN-39 computer. These components are off-the-shelf and are proposed for a future fighter aircraft. The Doppler-attitude system weighs approximately twice as much as the inertial guidance system and gives two to five-mile accuracy.

8.3.3.3 Radar-Transponder Position Fixing System. The radar-transponder system was studied in an effort to find a less expensive means of determining the position of the sensor aircraft. If the control aircraft has a highly accurate navigation system and a long range radar, the sensor carrying aircraft position in relation to the control aircraft can be determined. The control aircraft must have a radar with beacon interrogation capability and the sensor carrying aircraft must have transponder beacon. With such a system, the control aircraft will be able to determine the range and bearing to each sensor aircraft. The range and bearing information, used in conjunction with the position of the control aircraft, would provide the data for determining the geographical coordinates of the sensor aircraft.

This system could determine the position of the sensor carrying aircraft to ± 1.5 miles. However, this error must be added to the potential error of one to three miles of the control aircraft.

This system simplifies the equipment in the sensor carrying aircraft and complicates that in the control aircraft. Also, it requires that the sensor aircraft be at least 90 miles from the control aircraft at all times to prevent the radar side lobes from triggering the transponders.

The radar-transponder equipment are in Air Force inventory. The AN/APN-59 search radar and the AN/APN-69 transponder are made by Sperry Gyroscope Company. Similar equipment AN/APS-88 search radar and AN/APN-134 transponder are made by Bendix Corporation. The Bendix Corporation also makes the computer required with the system. The AN/APN-69 is an x-band, high-power, airborne radar beacon designed to serve as a navigational aid. The beacon operates in conjunction with any standard x-band radar equipped with beacon interrogating facilities. In response to an appropriate interrogating signal from a radar system, the beacon transmits a coded reply which results in a presentation on the radar indicator. The AN/APN-59 search radar is a small, lightweight, x-band radar. When used for beacon operation, it transmits an interrogating signal and then displays, in plan position, the space-coded identification of the automatic reply.

8.3.4 Altitude Measurement

The height above terrain must be known quite accurately to compensate the radiation measurements. Existing radio altimeters can measure the altitude above terrain very accurately. The output of the selected altimeter may require modification to provide a voltage output proportional to altitude. An aneroid barometer would not be usable to determine the height above terrain for most sections of the United States.

The RCA radio altimeter has the best weight, volume, cost, and accuracy of three altimeters studied. However, the unit is not in Air Force inventory yet. Comparable altimeters are made by Bendix or Emerson. Bendix makes the AN/APN-141 and Emerson makes the AN/APN-150.

8.3.5 Special Data System Components

The following special data system components were studied:

8.3.5.1 Tape Recorders. Two types of tape data recorders were studied for airborne use. An analog tape recorder made by Sanborn-Ampex provides a record-reproduce system which can handle signals from DC to 5000 cycles. For the smaller aircraft, when weight is a problem, a small recorder made by Mnemtron Corporation may be used.

The other type recorder considered was the digital stepping recorder made by Digi-Data Corporation. The Model DSR 1400 steps on command with the presence of each data input character, at stepping rates up to 300 steps per second. The stepping action of the capstan is accomplished by a multi-pole stepping motor. Reel, capstan motor, and transport control circuits are completely programmed by solid state devices.

8.3.5.2 Signal Conditioner Components. All the subsystems use signal conditioners. A signal conditioner is a device which processes a signal from an unusable form to a usable form. Signal conditioners such as DC amplifiers and AC amplifiers are available from several companies. A voltage analog repeater is another type of signal conditioner which can be secured from Gianinni Corporation. The special signal conditioner for correcting the dose rate readings for altitude and time will require design work but can be made up from commercially available subcomponents.

The computer must be designed to account for the altitude attenuation factor and the time delay factor.

(1) The effect of altitude attenuation may be approximated by an equation of the form

$$\phi(h) = \phi_o R_G a e^{-bh}$$

where

$\phi(h)$ is the flux at altitude

$\phi_o(h_o)$ is an arbitrary constant in γ $cm^{-2}sec^{-1}/R/hr$.

R_G is ground contamination in R/hr.

b,a are arbitrary constants

h is altitude

The value of the constants must be determined by a calibration procedure.

The radio altimeter output can be used to drive a logarithmic amplifier. The amplifier output with a volage divider network can solve the above equation.

(2) The effect of time on the dose rate readings can be approximated by the equation $R_t = R_G \left(t_o - \frac{H_1 + H_2}{2}\right)^{+1/2} \left(t - \frac{H_1 + H_2}{2}\right)^{-1.2}$ where R_G is the dose rate corrected for altitude effect, t_o is the time at which the measurement was made, H_1 is the time of the first explosion, H_2 is the time of the last explosion, t is the common reference time. A time synchronous motor can be used to drive a logarithmic potentiometer which in conjunction with a voltage divider network can solve the above equation. The computer should have controls for setting H_1, H_2, t, and a variation of the exponent.

(3) The effect of air density variation is small in comparison to the overall system inaccuracy. A correction could be applied by using an aneroid barometer to drive a potentiometer in the computer.

(4) The effect of temperature is small in comparison to the overall system inaccuracy. A temperature correction could be easily instrumented.

8.4 Variations of the Data Systems

Several variations of the Covey System and the Flock System were studied. Basically, each system processes the initial signals in the same way, except for the radar-transponder position fixing system where the geographical coordinates are determined in the mother aircraft.

8.4.1 Covey Telemetry Data System

The block diagram of the telemetry data system for both the Director aircraft and the Survey aircraft is shown in Figure 8.1. Starting with the five parameters – (1) latitude, (2) longitude, (3) dose rate, (4) time, and (5) altitude – the block diagram shows the signals being processed by signal conditioners. The dose rate, time, and altitude are combined in the signal conditioner to give dose rate corrected for altitude and time. The latitude and longitude signals are processed into a form compatible with telemetry. Each processed signal is then used to modulate the frequency of a subcarrier oscillator. The outputs of the subcarrier oscillators are combined in the signal multiplexer into a composite FM signal. The composite FM signal is used to modulate the RF carrier of the telemetry transmitter. The output of the transmitter is further amplified and transmitted to the control aircraft.

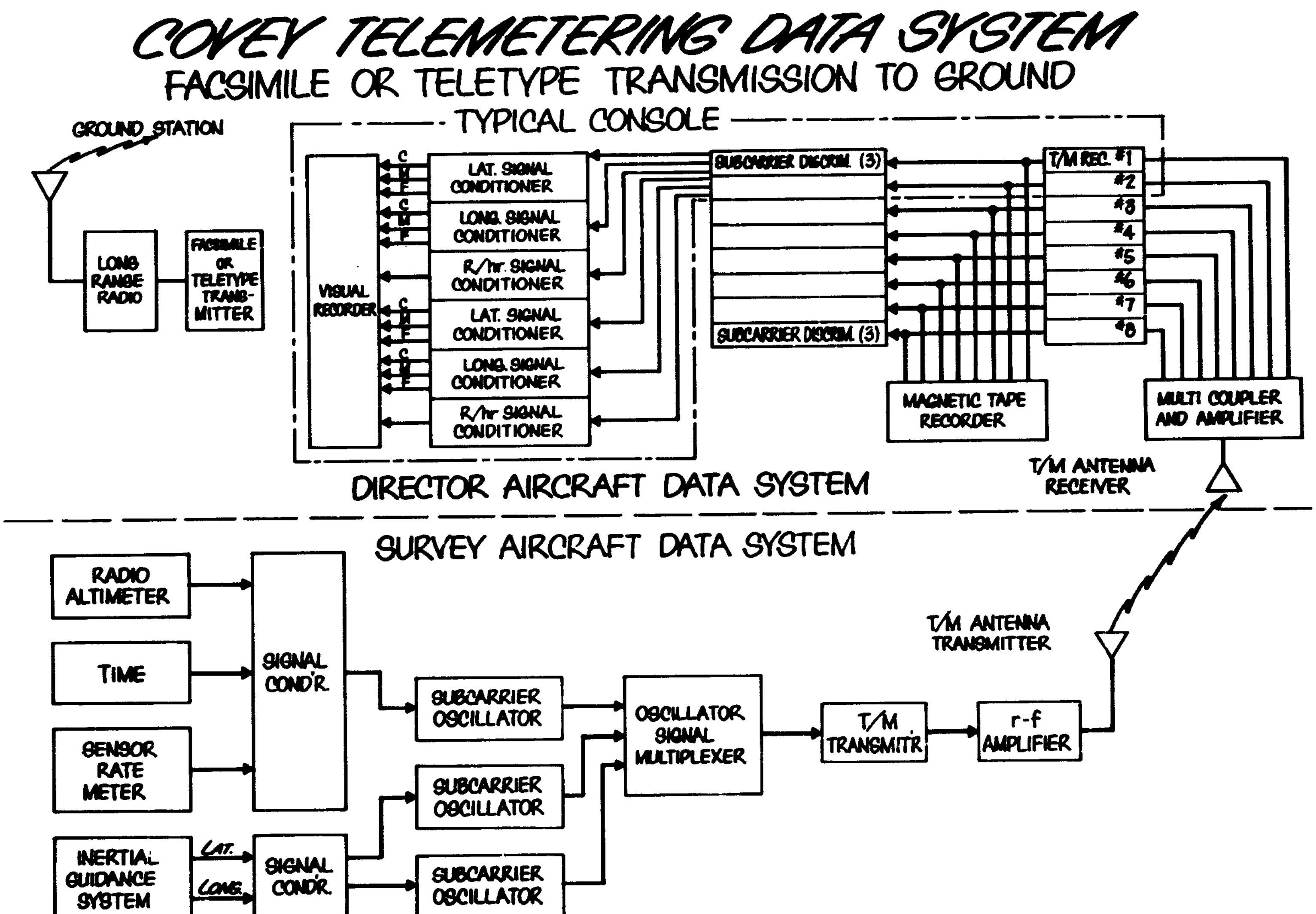

FIGURE 8.1

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Figure 8.2 shows the data system equipment for the Director aircraft installed in the Grumman Gulfstream. The installation of equipment for a survey aircraft is shown in Figure 8.3 for the Beech 18S and in Figure 8.4 for the Howard 500. Referring to Table 9.2 for cabin space comparisons, it can be seen that the equipment for the Director aircraft shown in Figure 8.2 for the Grumman Gulfstream can be similarly installed in the Howard 500 shown in Figure 8.4.

In the control aircraft, the telemetry signals from all the chicks are received on one antenna. A multicoupler is used to separate the telemetry signals and to route each signal to a receiver which is tuned to match the transmitting frequency of a particular chick. This receiver separates the composite subcarrier signals from the RF carrier and routes the composite signal to the subcarrier discriminators. The subcarrier discriminator reproduces the original data signal.

The reproduced signals - latitude, longitude, and dose rate - are processed by signal conditioners into a form compatible with the visual recorder. The latitude and the longitude signals must be read to the nearest minute. A signal repeated with three speed readout - coarse, medium, and fine - is recommended to make the data easily read.

After a data run has been completed, the visual record of the data - latitude, longitude, and dose rate - is plotted on

COVEY DIRECTOR AIRCRAFT

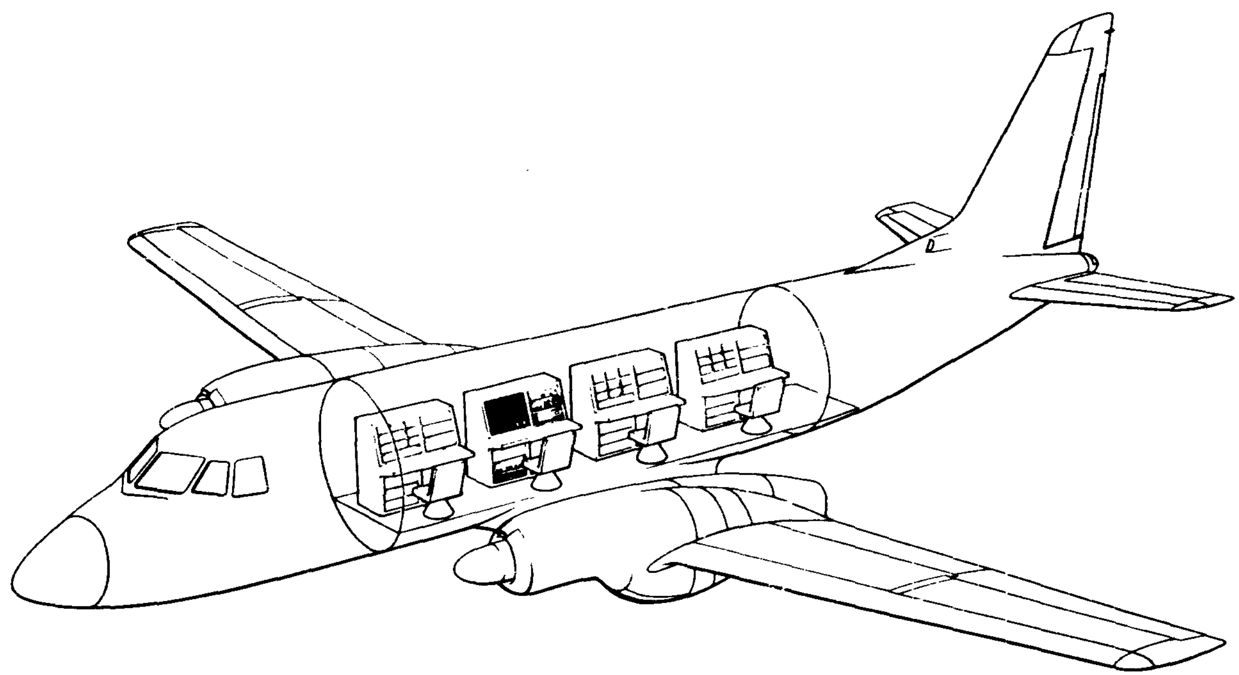

FIGURE 8.2

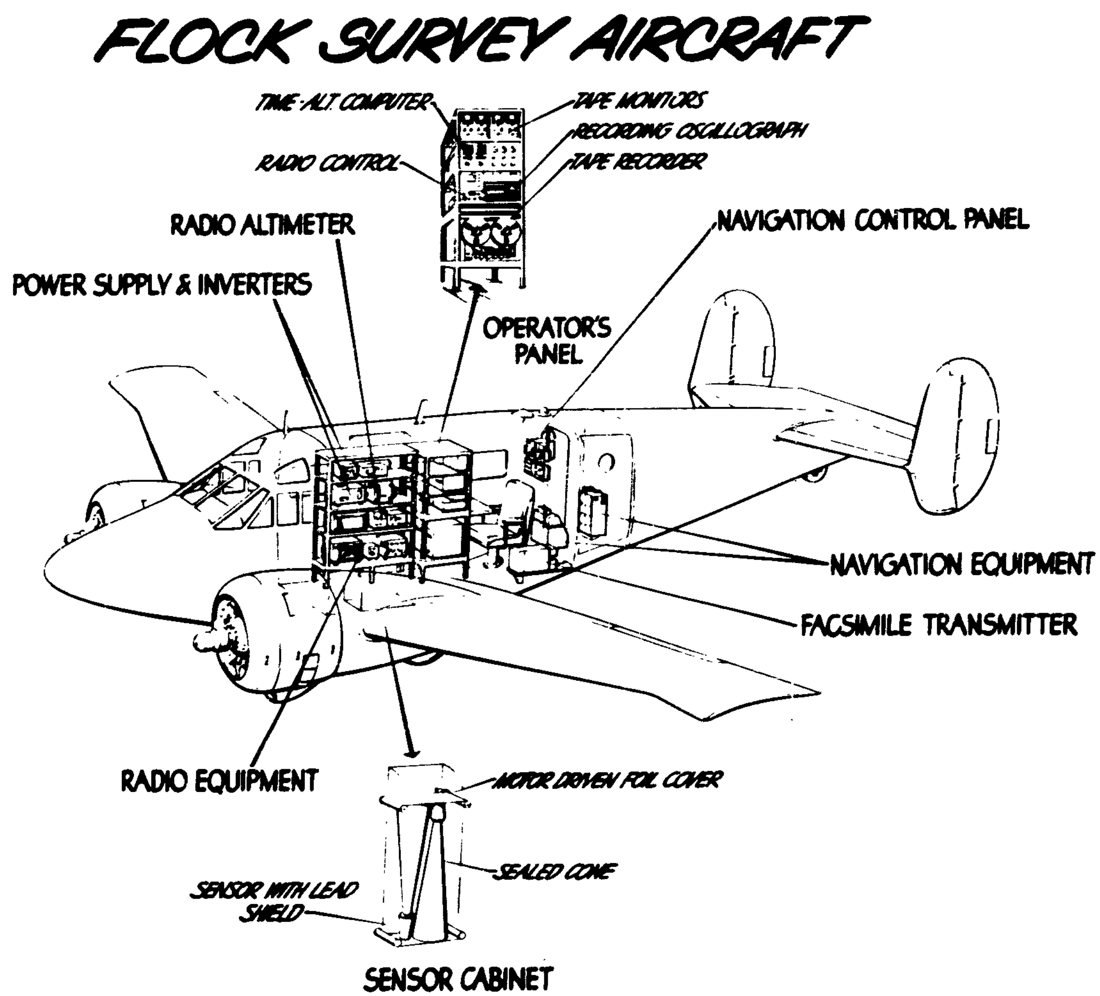

Fig. 8.3 Flock Survey Aircraft - Beech 18S

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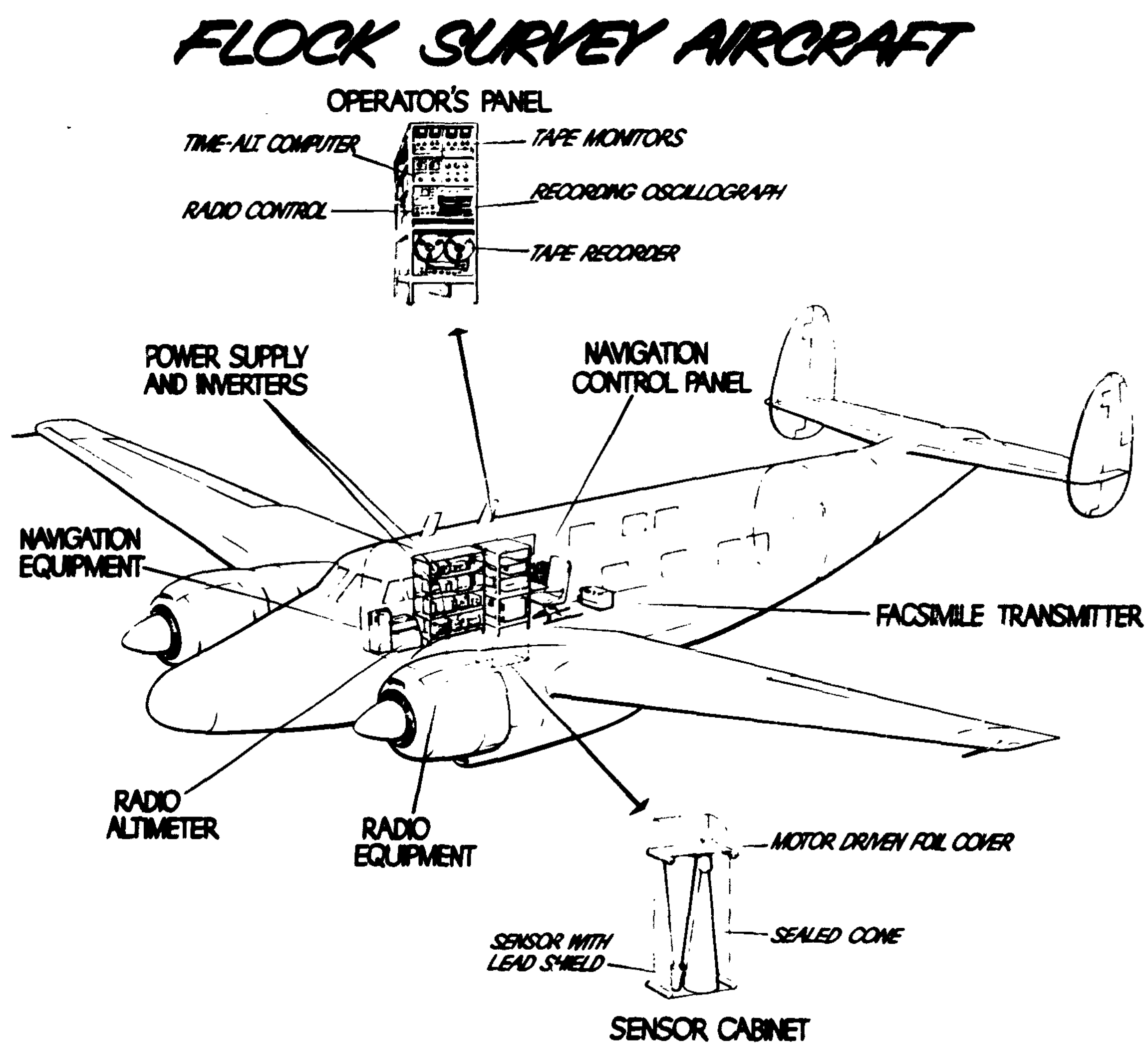

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Fig. 8.4 Flock Survey Aircraft - Howard 500

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an area map. The data plotter will plot only enough data to permit him to draw the isopleths of the fallout. When the isopleths have been drawn, the map may be transmitted by facsimile to the ground station. An alternate method would be to reduce the data to teletype format and punch it on teletype tape. The teletype tape would be used to operate a teletype transmitter to relay the data to the ground station.

8.4.2 Covey Telemetry Data System Utilizing a Sampling Technique

Figure 8.5 is identical to Figure 8.1, except that the director aircraft data system is simplified. By sampling the telemetry receiver outputs at two second intervals, the components and the amount of data will be reduced. The data will be displayed on two visual recorders instead of eight. The data processing and data transmission to ground will be accomplished in the same manner as for the more complex system.

8.4.3 Covey Telemetry Data System with Digital Data Transmission to the Ground Station

Referring to Figure 8.6, one can see the data system is identical to Figure 8.5 except the outputs of the signal conditioners in the mother aircraft are routed to a multiplexer and to a visual recorder. It is also evident that the more complex telemetering system of Figure 8.1 could be used. The multiplexer samples the data at a predetermined rate and relays one channel at a time to the encoder. The encoder converts the analog signal

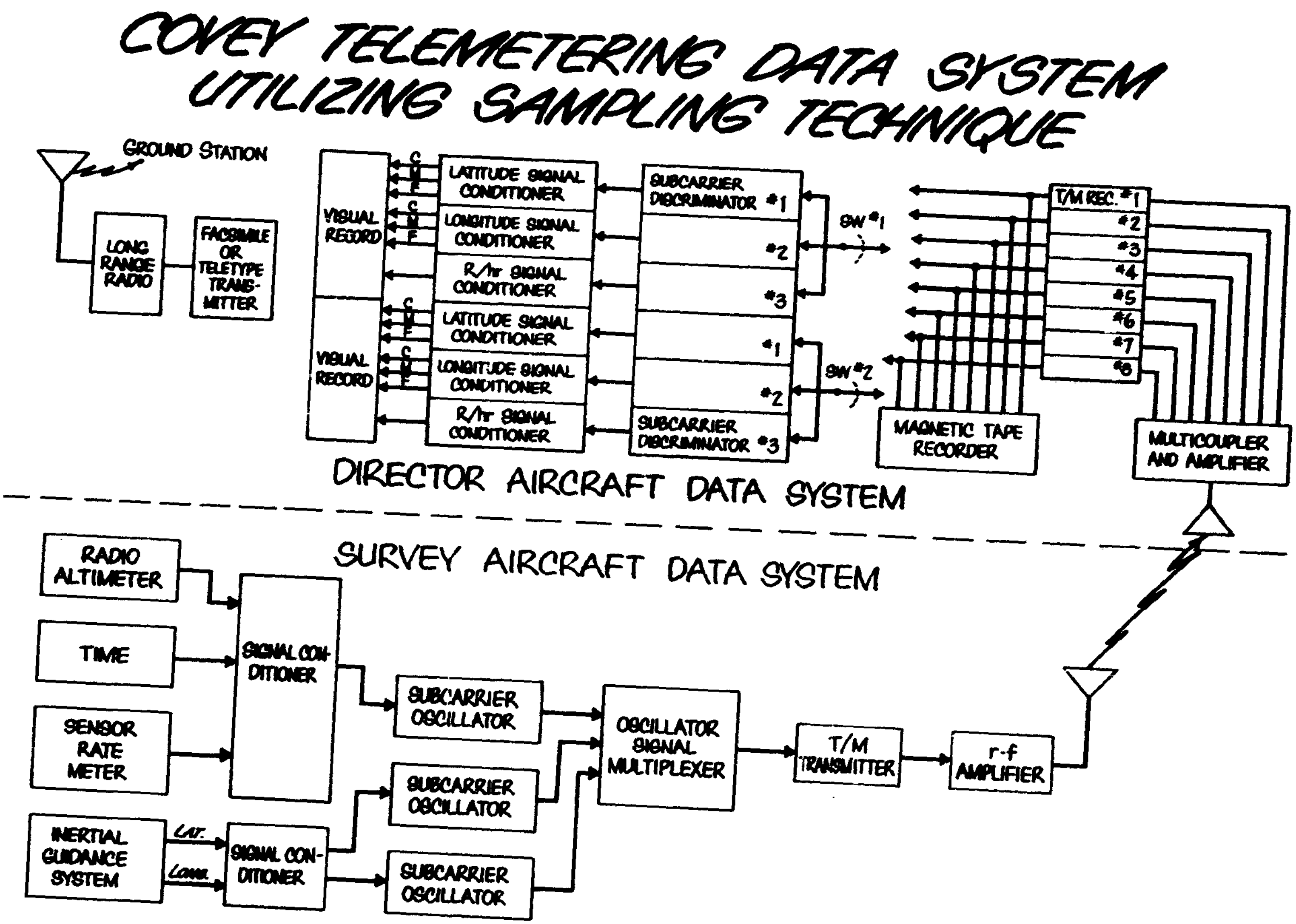

FIGURE 8.5

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COVEY TELEMETERING DATA SYSTEM

DIGITAL DATA TRANSMISSION TO GROUND

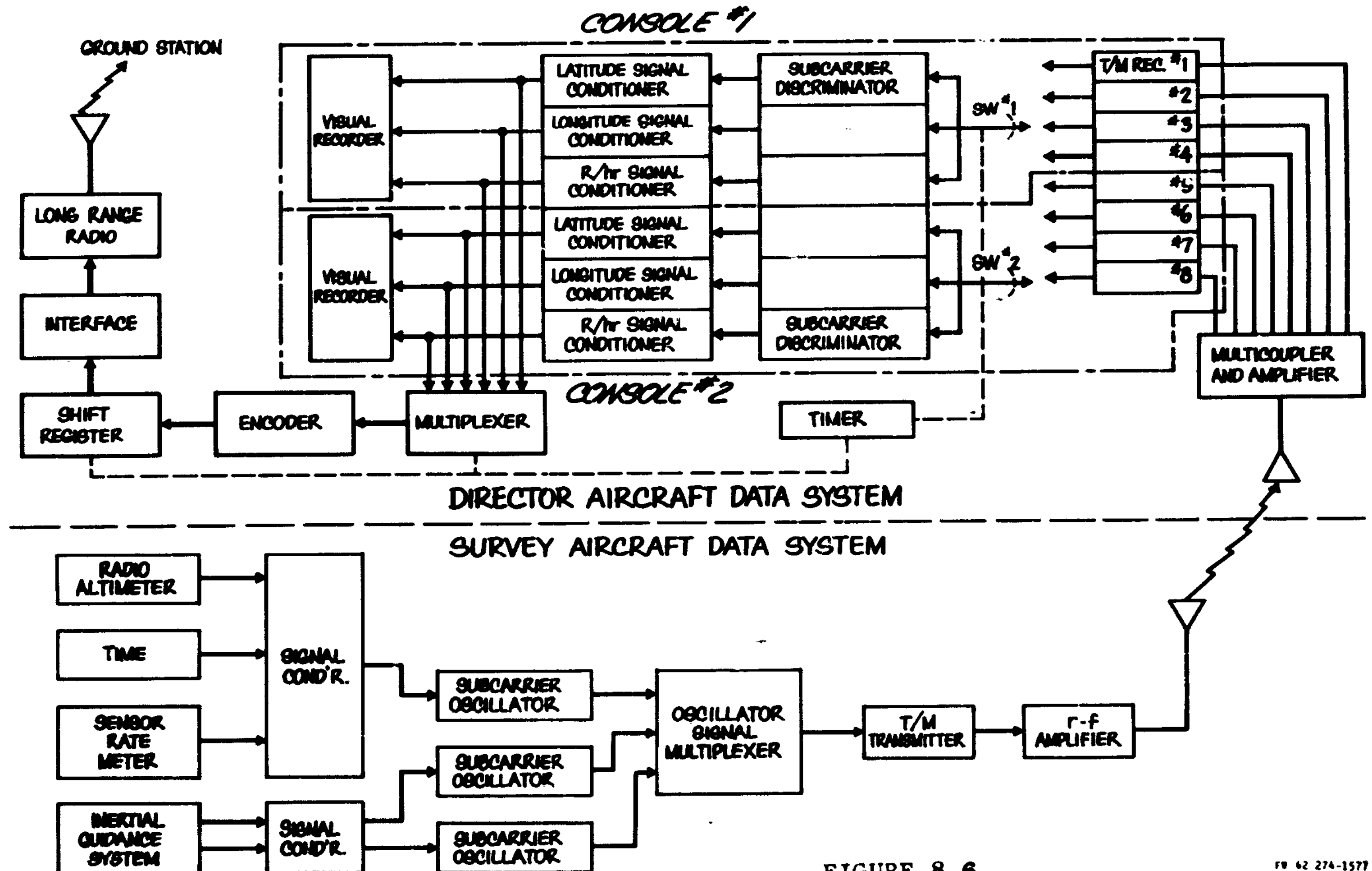

FIGURE 8.6

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to a digital format and sends it to the shift register. The shift register stores the digital data until commanded to transmit it to the interface equipment. The interface equipment processes the digital data so that it is compatible with the long range radio.

8.4.4 Covey Digital Data System with Data Limiting

The vast amount of data that would be generated in the event of a saturation attack on a national scale requires that a system be considered to limit the amount of data transmitted. A block diagram of a digital system using a threshold computer to limit the amount of data is shown in Figure 8.7. The data are processed as in the other systems through the signal conditioners. The analog output of the dose rate signal conditioner is routed to a threshold computer. The computer passes data only at discrete levels. At each level the discrete value of radiation is encoded to binary form. When the encoding is complete, gates to the latitude shift register and the longitude shift register are triggered in turn so that digital data in serial form are presented to a digital stepping recorder. The digital stepping recorder advances only on the command of each data input. A typical mission of 1000 miles would generate approximately six minutes of digital tape data using this technique. The flight director in each survey aircraft must note the highest reading obtained on each data run and the geographical coordinates of the reading.

COVEY DIGITAL DATA SYSTEM

- THRESHOLD COMPUTER & DIGITAL STEPPING COMPUTER IN SURVEY AIRCRAFT
- DIGITAL TRANSMISSION TO GROUND STATION

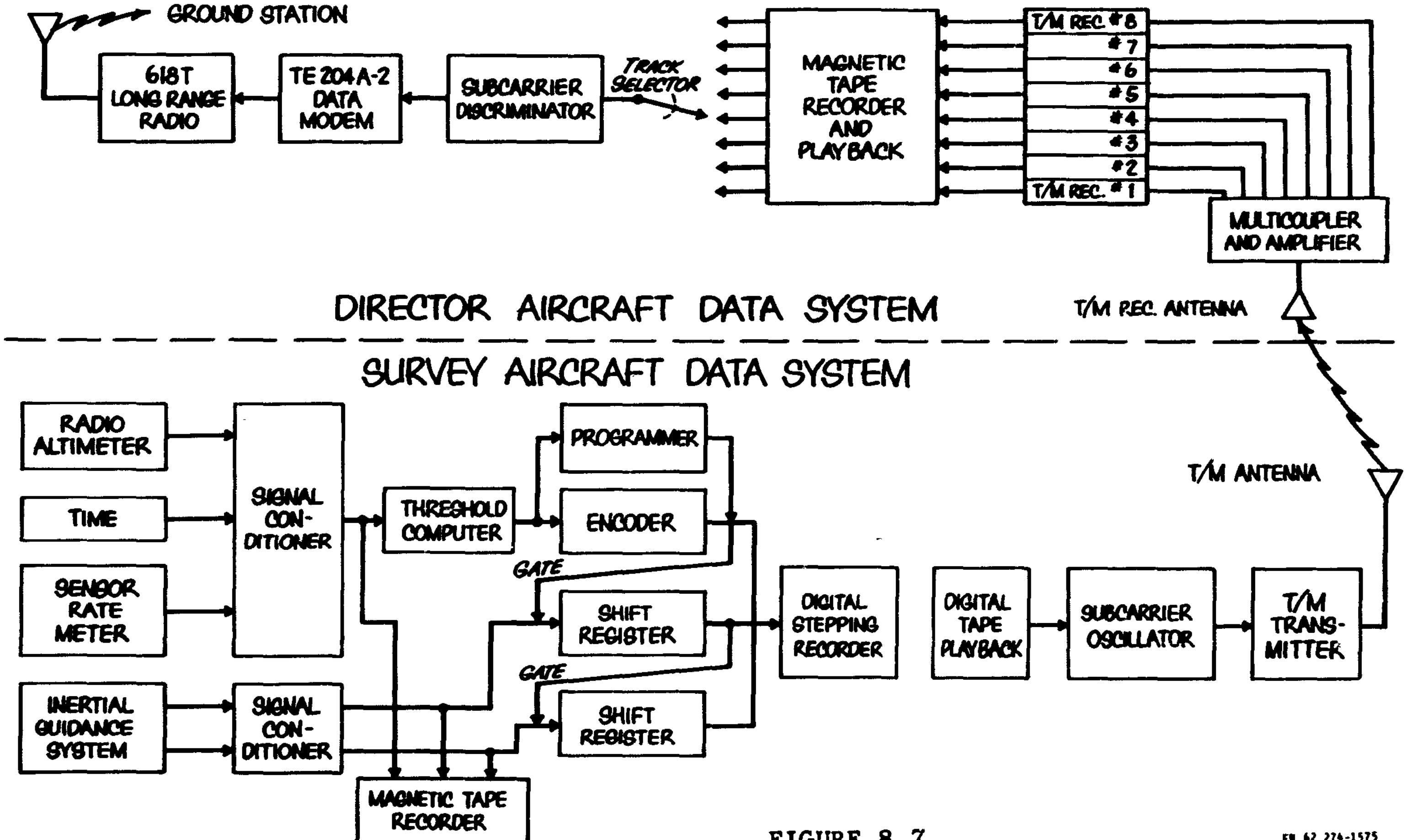

FIGURE 8.7

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The digital data transmission to the control aircraft would be accomplished by playing the digital data tape back into the telemetry transmission system. The data transmission may be made simultaneously from all the survey aircraft if each operates on a different telemetry frequency and the control aircraft is equipped with matching telemetry receivers as indicated in the block diagram. An alternate method would be for the survey aircraft to space their transmission of data so that no overlap occurs. This would require only one telemetry receiver in the control aircraft. The data system in the control aircraft is essentially a tape recorder and a tape playback system. In the block diagram shown, a separate tape channel is provided for each survey aircraft. During playback one channel at a time is played back putting the data in serial form for transmission to the ground. The playback rate is set at 75 bits per second to be compatible with the long range radio. In the system where the survey aircraft space their transmission, the control aircraft will record the data on one channel of tape as it will already be in serial form. In each case the hot line data will be relayed by audio to the control aircraft and transmitted to ground by teletype over the long range radio.

Each survey aircraft has two tape recorders. One is the digital stepping recorder and the other is a backup recorder which records all data prior to the threshold computer. The backup recorder provides redundancy and also a source of more detailed data if it is required.

8.4.5 Covey System with Combined Radar and Telemetering Data System

The block diagram shown in Figure 8.8 shows that the parameters - altitude, time, and dose rate - are processed as in the other data systems. The overall system appears to be less complex; however, the precision timing required may make it more difficult to function correctly. When the radar interrogator in the mother aircraft transmits a particular code to the chick aircraft, the transponder in the chick replies and also closes a relay in the data transmission link. The transponder reply causes the radar computer in the mother aircraft to compute the range and azimuth of the chieck. The azimuth and range are resolved by a computer, which is also part of the navigation system, into latitude and longitude. At the same time, the dose rate is transmitted to the mother aircraft by the telemetering link. The dose rate, latitude, and longitude may be displayed on a visual recorder as in the other data systems and transmitted by a facsimile or teletype to the ground stations.

8.4.6 Flock Data System with Facsimile or Teletype Transmission to Ground

Referring to Figure 8.9, one can see the data inputs are processed as for the Covey Data Systems. The outputs of the signal conditioners, however, are displayed on a visual recorder

COVEY COMBINED RADAR & TELEMETERING DATA SYSTEM
FACSIMILE OR TELETYPE TRANSMISSION TO GROUND STATION

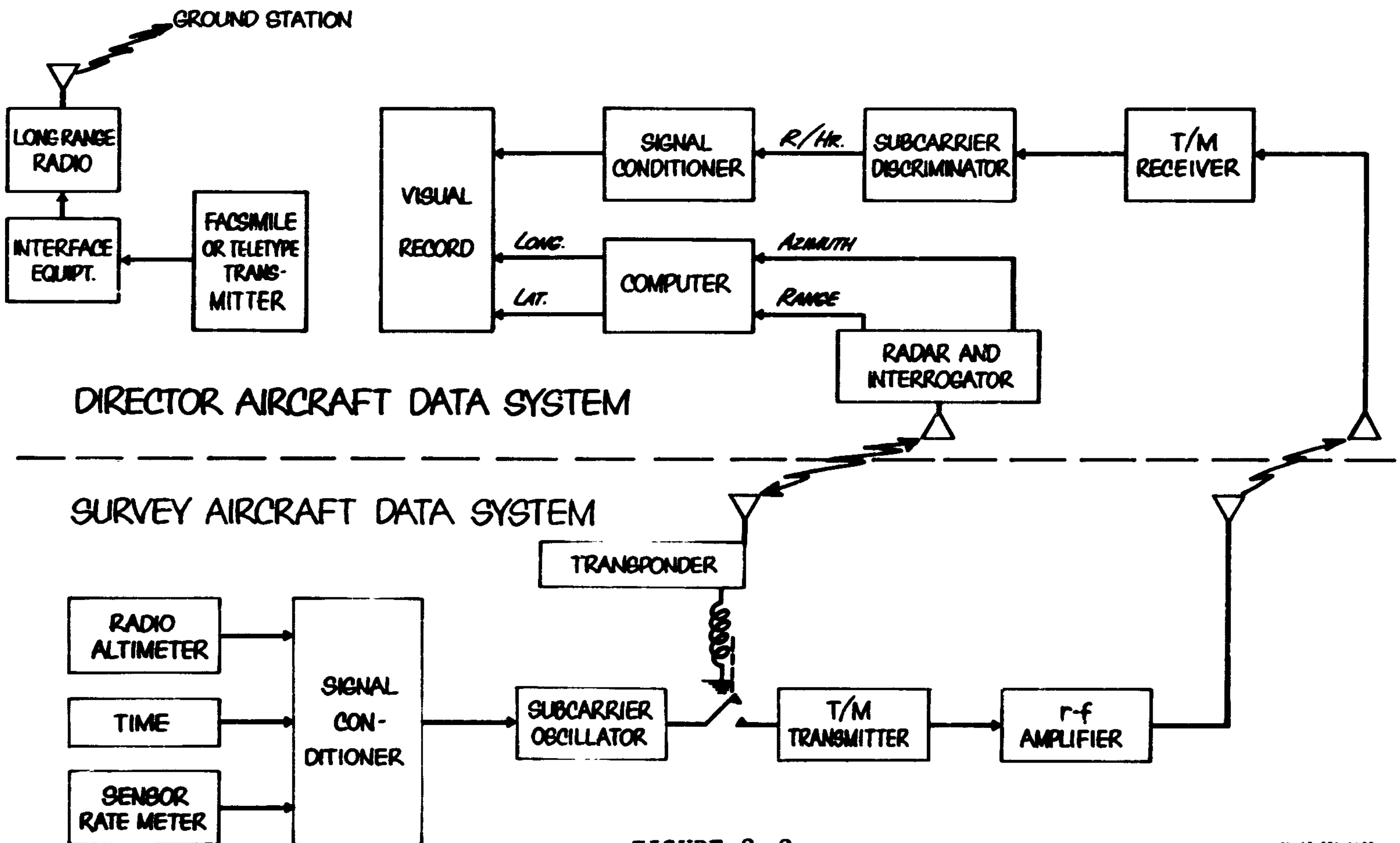

FIGURE 8.8

FLOCK DATA SYSTEM

FACSIMILE OR TELETYPE TRANSMISSION TO GROUND STATION

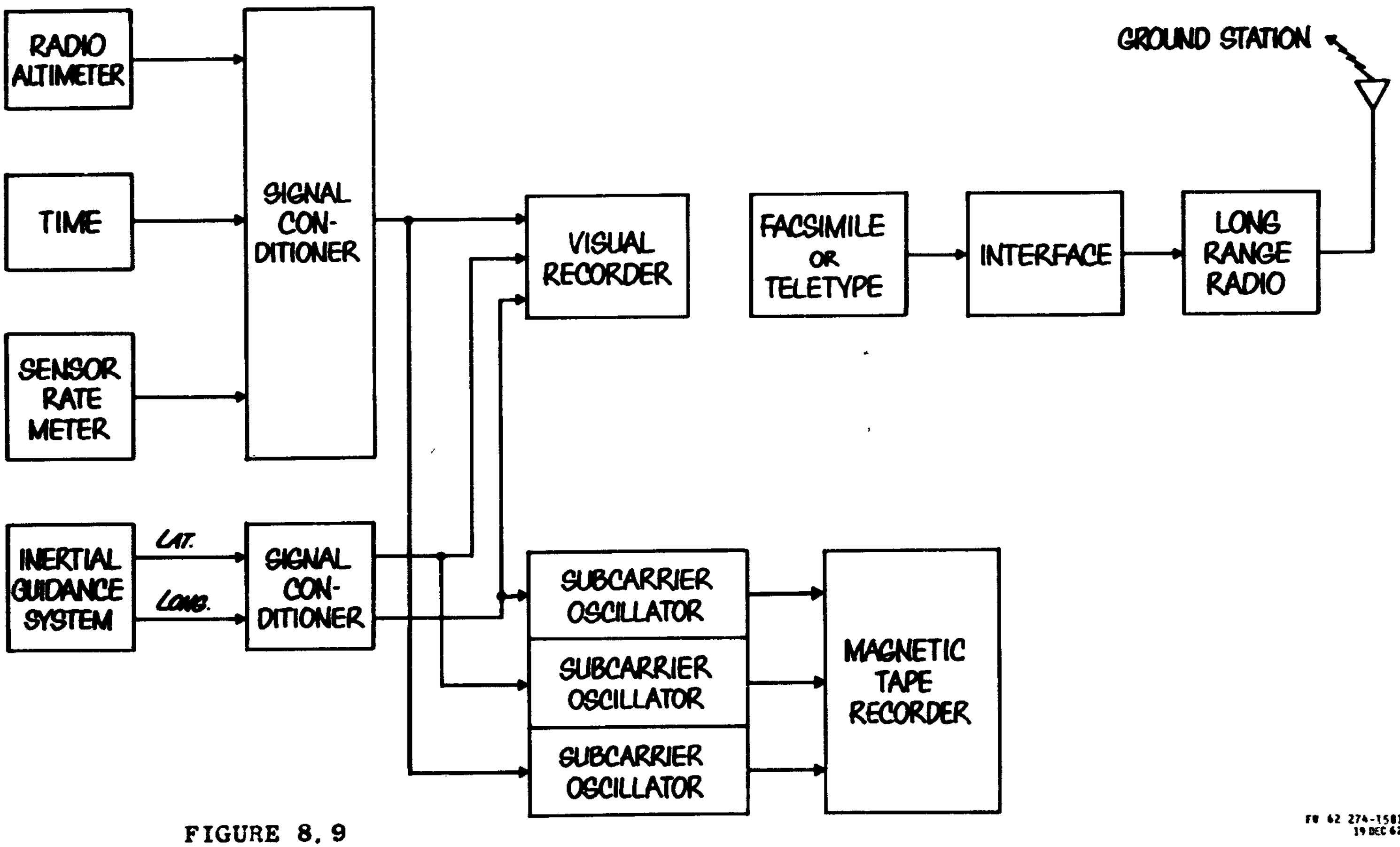

FIGURE 8.9

recorded in the Flock aircraft. The data are plotted on an area map after completion of a run as for the Covey System. The area map is transmitted by facsimile over long range radio to ground. The data may also be punched into teletype tape and the tape used to operate the teleprinter.

8.4.7 Flock Data System with Digital Data Transmission to Ground

The block diagram shown in Figure 8.10 shows that the signal inputs are processed as in the other systems up through the signal conditioners. The analog outputs of the signal conditioners are routed to a magnetic tape recorder and to a multiplexer. The multiplexer samples the analog data on command from a program timer and connects one signal at a time to an encoder. The encoder converts the analog data to digital data. The output of the encoder is stored in a shift register. The output of the shift register is 75 bits per second consisting of the original signals in digital form, or real time in digital form, and of identification pulses. The output of the shift register is processed by the interface equipment into a form compatible with the long range radio for transmission to the ground.

8.4.8 Flock Digital Data System with Data Limiting

The vast amount of data that would be generated in the event of a saturation attack and the complex data transmission to ground from continuously transmitting Flock aircraft makes the

SURVEY AIRCRAFT DATA SYSTEM
DIGITAL DATA TRANSMISSION TO GROUND

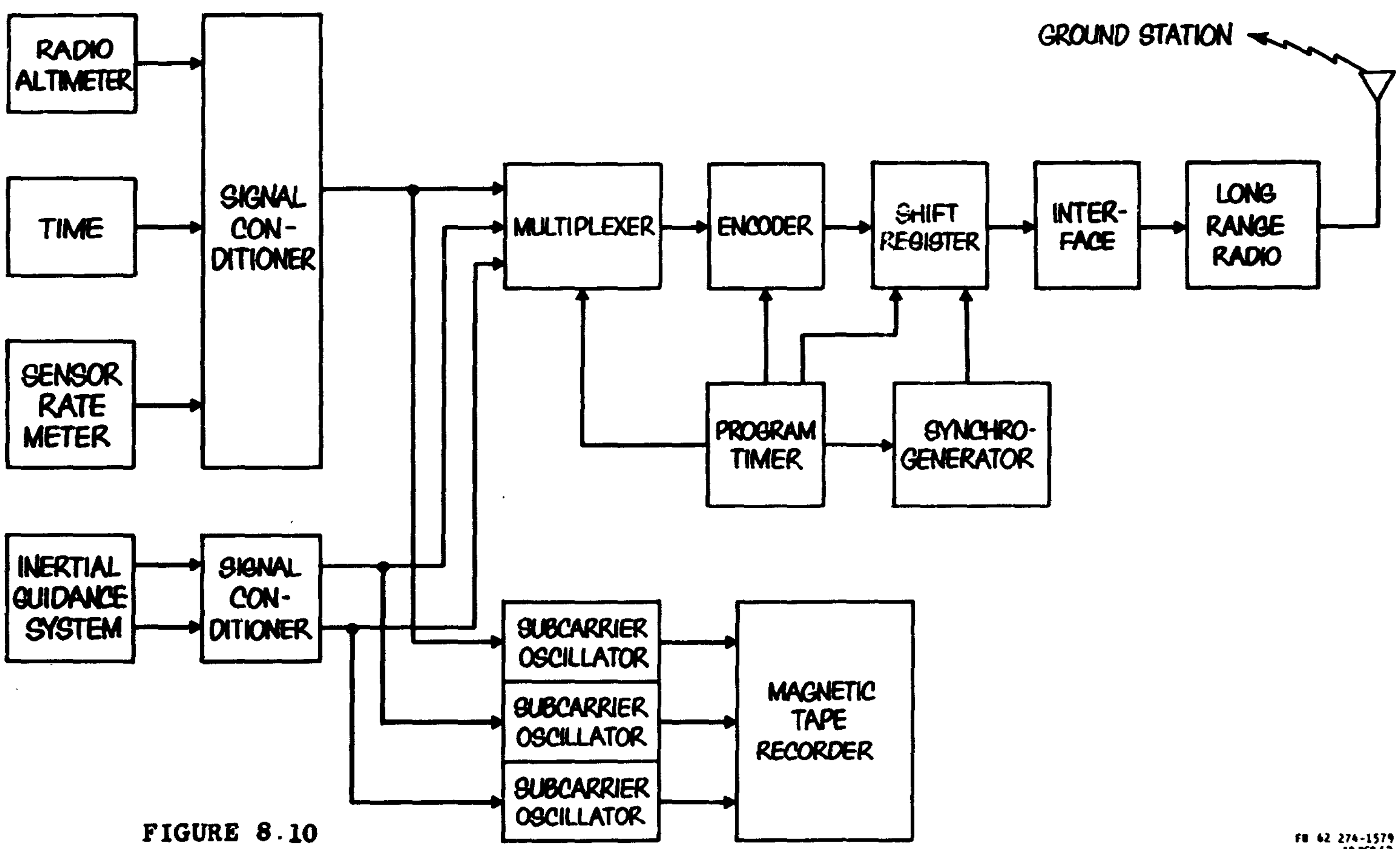

FIGURE 8.10

study of a data limiting system a necessity. The data system shown in Figure 8.11 is the same as that outlined in paragraph 8.4.4 except the data transmission will be to ground using long range radio instead of telemetry to the control aircraft. The short digital tape for the entire flight would permit the aircraft to space their transmission to the ground which would reduce the communication load at the ground station. Each Flock aircraft will have two tape recorders. One is the digital stepping recorder and the other is a backup recorder which records all data prior to the threshold computer.

8.4.9 Convertible Data System

Referring to Figure 8.12, one can see that the data system is similar to the Flock Data Systems described above except a telemetering link has been added. The addition of the telemetering link would permit the sensor carrying aircraft to operate as part of the Covey System or as part of the Flock System.

8.5 Ground Data Handling System

Each of the proposed aircraft-to-ground data transmission systems require a different data handling technique in the ground stations. The CD Regional Headquarters will have the radio system most likely to survive. Each headquarters is to have underground radio facility with telescoping antennae. The antennae will remain retracted until after the initial burst. The eight CD Regional Headquarters are so situated that the data gathering

SURVEY AIRCRAFT DIGITAL DATA SYSTEM

- THRESHOLD COMPUTER AND DIGITAL STEPPING RECORDER
- DIGITAL TRANSMISSION TO GROUND STATION

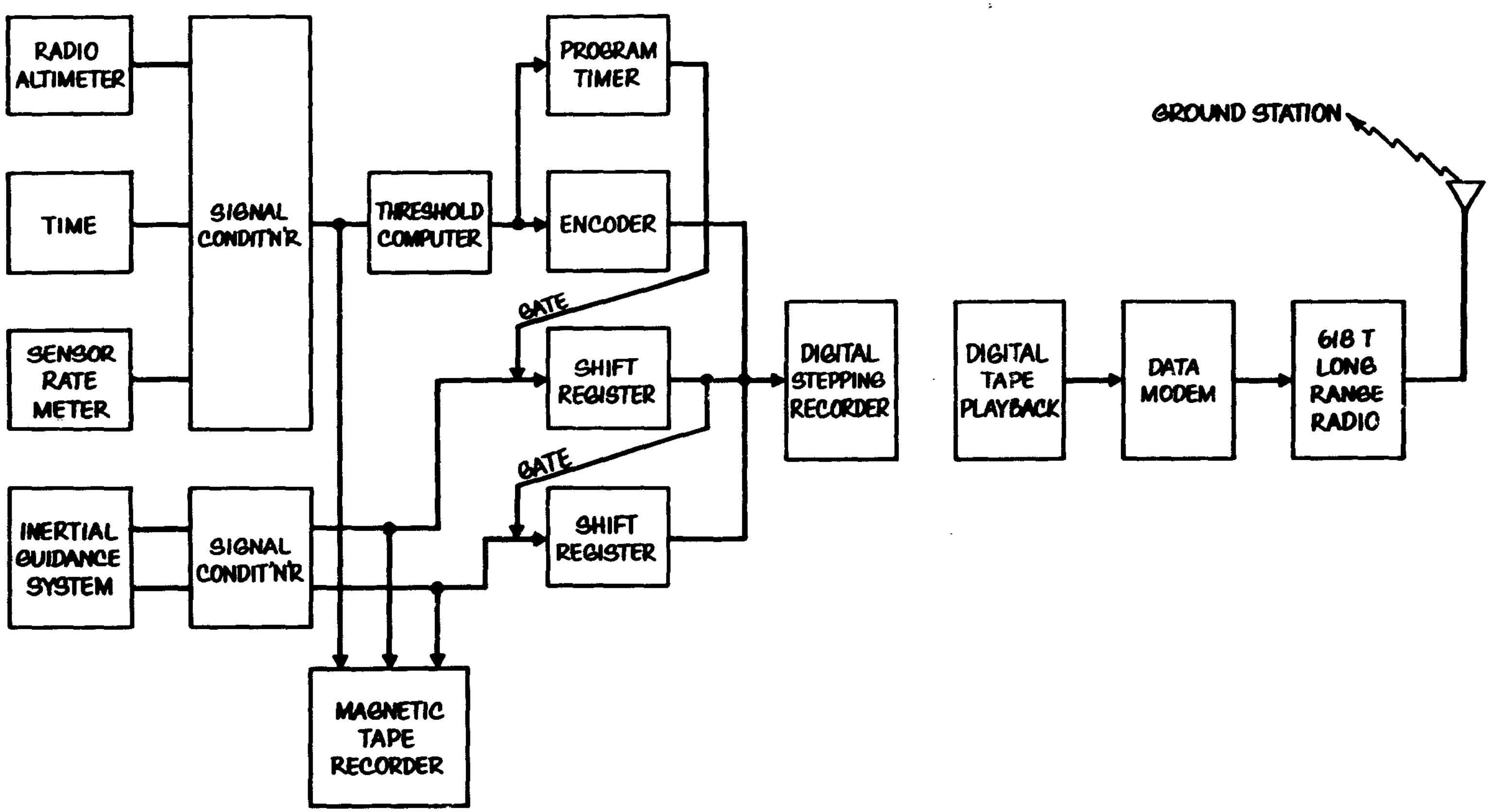

FIGURE 8.11

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CONVERTIBLE DATA SYSTEM
OPERABLE WITH COVEY OR FLOCK SYSTEM

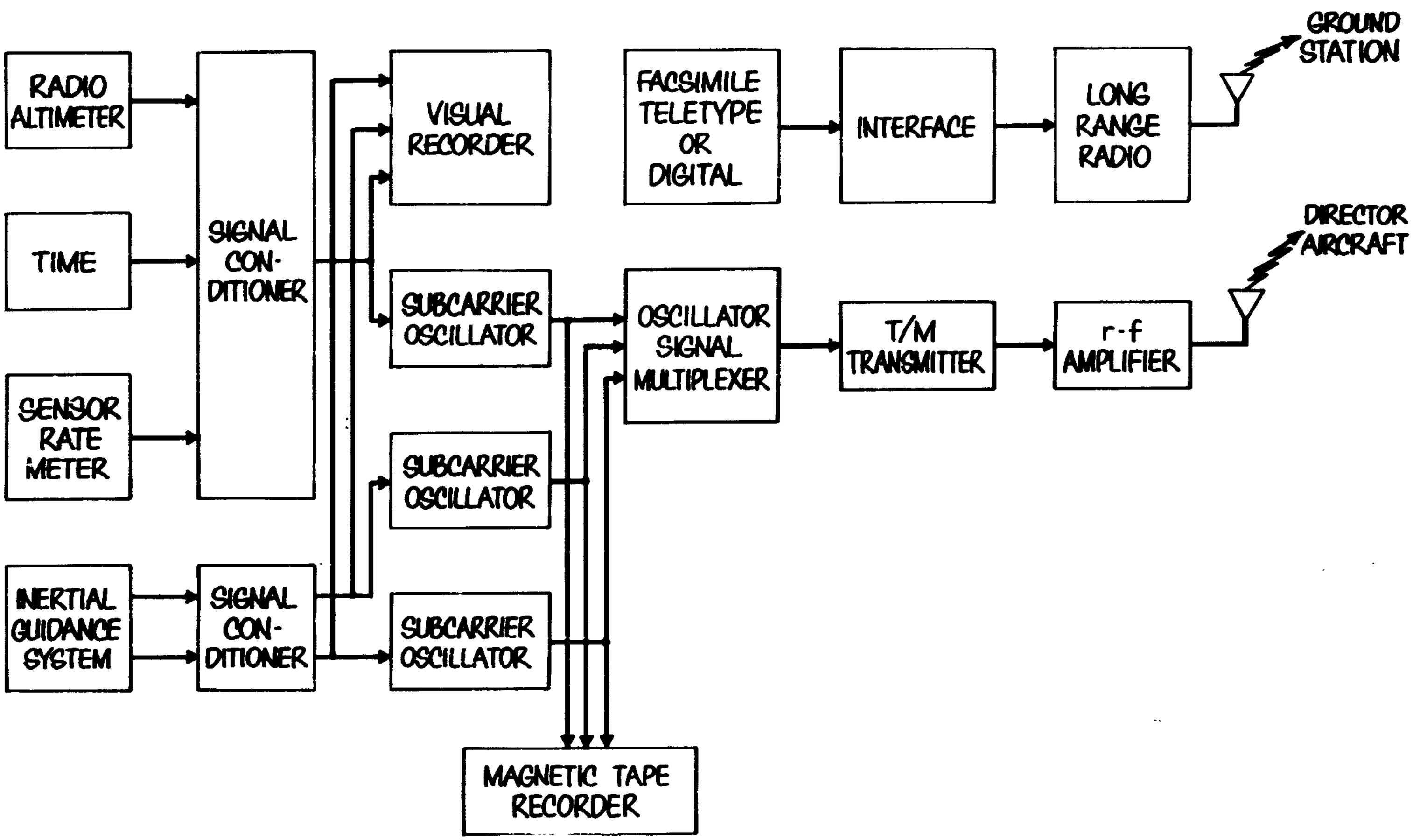

FIGURE 8 12

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19 DEC 62

aircraft should be able to communicate with at least one of the centers at all times with the long range radio. Each of the eight centers is equipped with Collins Radio receiving equipment such as the 50 E-1 receiver. The 50 E-1 receiver is a servo tuned SSB (single side band) HF (high frequency) receiving set. The set may be tuned in 1 kc (kilocycle) steps from 2 to 29.999 mc (megacycles). Operation is possible on either sideband or both sidebands independently. The received signal may be amplitude modulated, or with additional accessory equipment, teletype, or facsimile.

8.5.1 Covey Data System Using Facsimile Data Transmission

As previously stated, the control aircraft will transmit an 8-1/2 x 11 map of plotted data to the ground station. The ground station will receive the facsimile map on a facsimile receiver operating in conjunction with a long range radio receiver. The received data will be prepared for retransmission by facsimile to the classified center. The complete data map in the most easily interpreted form would be available to the using agency in 10 to 15 minutes after the control aircraft transmitted the data.

8.5.2 Covey Data System Using Teletype Data Transmission

The control aircraft will transmit data in "point" format, i.e., latitude, longitude, and R/hr over its teleprinter system via long range radio. The ground station will receive the teletyped data via long range radio receiver system. The teletype device will type the data on paper and will punch a teletype tape. At this point, the data may be plotted on area maps and transmitted by facsimile, or the data may be transmitted by teletype to the using agency. The teletype system will take approximately 30 minutes to an hour to get the data from the control aircraft to the using agency.

8.5.3 Covey Data System Using Digital Time Transmission

The control aircraft will be transmitting data continuously when the sensor carrying aircraft are flying over fallout. In case of a saturation nuclear attack, the sensor carrying aircraft would be measuring radiation almost continuously in some areas of the country. Consequently, the amount of data to be handled will be large. To avoid the loss of data, each ground station must be equipped with a tape recorder and data playback. For normal mode of operation, the data will be received on the long range radio with a Collins Radio Data Modem Interface as accessory equipment. The interface equipment has a synchronization detector which selects one of the low frequencies and one of the high frequencies for synchronization of receiver base to received signal. The output of the interface equipment will go to magnetic tape and to a data relay device. The data relay device such as Nacon I or Nacon II will transmit the data to the classified center.

At the classified center the data will be received in its communication center on a Kineplex Data Modem. The received digital data will go to a buffer memory which permits the incoming data to be gapped on tape in computer format. The special computer formats, such as parity, end of record marks, write initiate signal, beginning of block, etc., are added to the tape. The computer tape is then placed on the computer and instructions given to print out the data in respective R/hr format (1, 3, 10, 30, 100, 300, 1000) on digital tape. The digital tape with the reduced amount of data is then played back into digital magnetic tape plotting system. F. L. Mosely Company, Model 44A magnetic tape control unit will accept data from IBM computer tapes recorded in the binary or binary-coded-decimal mode. The same company makes the Model 44B tape converter which converts binary data at a sapacity of 12 binary bits per axis, and with a resolution of 4096 points for each axis. The output of the tape converter is used to drive an X-Y recorder. The X-Y recorder will print out all the 1 R/hr data points, then will print out the 3 R/hr data points and so on until all the data are plotted. The plotted data on the X-Y chart will then be transferred to the map of the United States and isopleths drawn.

8.5.4 Covey Data System Using Digital Data Limiting

The reduction of the amount of transmitted data greatly reduces the ground system workload. The equipment required at the ground station and the national center will be the same as for the continuous system. However, the processing time will be greatly reduced.

8.5.5 Flock Data System Using Facsimile Data Transmission

The Flock aircraft will transmit data on an area map to the ground station by using a facsimile transmitter. The ground station will use the received facsimile map to plot the data on a large area map. The ground station may have to wait for several Flock aircraft to transmit their data before sufficient data will be available to plot the isopleths. The ground station will use facsimile transmission to forward the large area map to the using agency. The data will be available to the using agency in a matter of minutes.

8.5.6 Flock Data System Using Teletype Data Transmission

The Flock aircraft will transmit data to the ground station in latitude, longitude, and R/hr format on a teletype transmitter. The ground stations will plot the data on a large area map. When sufficient data are available, the ground station will transmit the data by facsimile to the using agency, or it will transmit the raw data. The data should be available to the using agency approximately 30 minutes after receipt by the ground station.

8.5.7 Flock Data System Using Digital Data Transmission

The Flock aircraft will transmit digital data continuously when the aircraft is over a fallout area. This continuous transmission requires that more than one receiver be available in the ground station. By using a multicoupler, the antenna at the ground station can handle several simultaneous transmissions. The handling of the multiple channels of received data requires the use of a TE-202 Data Modem and a tape recorder for backup. The TE-202 Data Modem can handle up to 40 parallel synchronous data signals each operating at 75 bits per second. The data can be handled in the same manner as for the Covey System at the using agency and will require the same length of time to reduce the data. The tape recorder playback will prevent the loss of data in case a problem develops in the data transmission channel on the ground.

8.5.8 Flock Data System Using Digital Data Limiting

The limiting of the data to discrete levels and the recording of the data on a digital stepping recorder reduces the total transmission time to approximately six minutes. The short transmission time permits the survey aircraft to space their transmissions without danger of overlapping. The elimination of overlapping communications eliminates the requirement for multiple radio receivers in each CD Regional Headquarters. Also, the need for the large TE-202 Data Modem is reduced to a single channel data modem. The data processing in the national center will be greatly reduced by the limited amount of data.

8.6 Data System Evaluation

The evaluation of the data system must be based on accuracy, response time, and cost. All data systems have the same relative accuracy. This leaves only cost and response time for the system evaluation.

Table 8.1 is an estimate of the cost of the components for the variations of the data systems. The table indicates that the Flock System utilizing 50 survey aircraft with a teletype data system is the least expensive. The Flock System with the facsimile data system is only slightly higher. The Flock System with digital limiting is the next best.

Table 8.2 shows the estimated data processing times for the variations of the data system. The Flock section of the table is based on a 648-minute mission with 50 aircraft and a 336-minute mission with 100 aircraft. The Flock Data System using the facsimile technique and 100 survey aircraft has the fastest data response time.

Based on the above results, the Flock Data System using facsimile transmission is recommended as the first choice. Teletype transmission is so close to the facsimile transmission in cost and response that it should be grouped with the facsimile as first choice.

When all factors are considered, such as flight coordination, in-flight data reduction, simplification of communications and automation, the Covey System using five control aircraft and digital data limiting, is recommended as second choice.

Table 8.1

ESTIMATE OF TOTAL DATA SYSTEM COST

	No. of Items	Facsimile	No. of Items	Teletype	No. of Items	Digital	No. of Items	Digital Limited
Covey T/M wo/Switching								
10 Control A/C		$ 2,120,000		$ 2,120,000		$ 2,250,000		$ 1,120,000
50 Survey A/C		1,750,000		1,750,000		1,750,000		2,500,000
8 Ground System	8(A)	48,000	8(D)	28,000	4(C)	32,000	4(C)	32,000
	8(B)	28,000			12(D)	42,000	12(D)	42,000
					8(E)	280,000		
		3,946,000		3,898,000		4,354,000		3,974,000
Covey T/M w/Switching								
10 Control A/C		1,120,000		1,120,000		1,250,000		750,000
50 Survey A/C		1,750,000		1,750,000		1,750,000		2,500,000
Ground System	8(A)	48,000	8(D)	28,000	4(C)	32,000	4(C)	32,000
	8(B)	28,000			12(D)	42,000	12(D)	42,000
					8(E)	280,000	8(E)	380,000
		3,946,000		2,898,000		3,354,000		3,604,000
Covey T/M w/Switching								
5 Control A/C		1,060,000		1,120,000		1,250,000		560,000
50 Survey A/C		1,750,000		1,750,000		1,750,000		2,500,000
Ground System	8(A)	48,000	8(D)	28,000	8(D)	28,000	8(D)	28,000
	8(B)	28,000			8(E)	280,000	8(E)	280,000
		2,876,000		2,898,000		3,308,000		3,368,000
Flock System								
50 Survey A/C		2,500,000		2,500,000		2,500,000		2,500,000
Ground System	8(A)	48,000	8(D)	28,000	8(C)	64,000	8(E)	280,000
	8(B)	28,000			8(E)	280,000	8(D)	28,000
					64(D)	224,000		
		2,576,000		2,528,000		3,068,000		2,808,000
Flock System								
100 Survey A/C		5,000,000		5,000,000		5,000,000		5,000,000
Ground System	8(C)	64,000	8(C)	64,000	88(C)	704,000	8(C)	64,000
	16(A)	136,000	16(D)	56,000	8(E)	280,000	8(E)	280,000
	8(B)	28,000			8(D)	504,000	16(D)	56,000
		5,228,000		5,120,000		6,488,000		5,300,000

(A) – Facsimile Receiver; (B) – Facsimile Transmitter; (C) – Radio Receiver; (D) – Data Modem; (E) – Tape Recorder

Table 8.2
ESTIMATE OF TOTAL DATA PROCESSING TIME FOR NATIONAL COVERAGE INCLUDING FLIGHT TIME

Flock

	Facsimile		Teletype		Digital		Digital Limiting	
Mission Time	648 min	336 min	648 min	336 min	648 min	336 min	648 min	336 min
Process Data	30	20	50	40	--	--	--	--
Xmt to Gnd	60	60	60	60	--	--	60	60
Gnd to Plot	20	20	--	--	--	--	--	--
Xmt to Nat'l Cn'tr	6	6	5	5	--	--	--	--
Nat'l to Cn'tr to Plot	60	60	120	120	60	60	60	60
Data Tape	--	--	--	--	60	60	60	60
Tape to Comp Tape	--	--	--	--	60	60	60	60
Computer Proc	--	--	--	--	240	480	60	60
X-Y Plot	--	--	--	--	10	10	10	10
Total Time	13 hrs 44 min	8 hr 10 min	14 hrs 43 min	9 hrs 9 min	17 hrs 58 min	16 hrs 34 min	15 hrs 58 min	10 hrs 34 min

Covey

	Facsimile		Teletype		Digital		Digital Limiting	
Mission Time	648 min	596 min	648 min	596 min	648 min	596 min	648 min	596 min
Process Data	30	30	50	50	--	--	--	--
Xmt to Gnd	6	6	5	5	--	--	60	60
Gnd to Plot	--	--	--	--	--	--	--	--
Xmt to Nat'l to Cn'tr	6	6	5	5	--	--	--	--
Nat'l to Cn'tr to Plot	60	60	120	120	60	60	60	60
Computer	--	--	--	--	120	120	60	60
X-Y Plot	--	--	--	--	10	10	10	10
Data Tape	--	--	--	--	120	120	60	60
Total Time	12 hrs 30 min	11 hrs 18 min	13 hrs 48 min	12 hrs 36 min	15 hrs 48 min	14 hrs 36 min	14 hrs 58 min	13 hrs 46 min

9. AIRCRAFT

Two general types of survey systems are being considered. One consists of a number of low flying survey aircraft, each carrying survey apparatus and transmission equipment to relay the data to ground stations. The other system involves a high altitude control aircraft hovering in the air within data transmission range of the low flying survey aircraft assigned to it. This control aircraft receives data from the survey aircraft, processes it, and transmits the results to a ground station.

In this section, operational and performance requirements of the survey and director aircraft and estimates of investment and operational costs of candidate aircraft that meet these requirements are given. Operational costs are based upon an operational concept where the aerial monitoring system is attached to and is co-located with Reserve Recovery units now assigned to non-military dispersed airports.

9.1 Operational and Performance Requirements

The operational and performance characteristics of the survey aircraft will have a major effect upon the design and cost of survey system. There are many trade-offs between range, speed, initial cost, payload, and operating costs of various aircraft to be considered, each of which will affect the cost of the system. The response time at which the data can be presented in the form of radiation contours varies with the range and speed of the survey aircraft and the method used to process and transmit the data. Range and speed are primary factors in determining the number of aircraft required for the system, and consequently, the cost. Thus, more than one type of aircraft must be analyzed in designing the system.

The survey aircraft must have a high probability of surviving the set of conditions that result in the use of the monitoring system. This indicates that they must be based at existing civilian airports which are at a safe distance from expected burst points. Basing at these remote airports, many of which have limited maintenance facilities, increases the operating costs and precludes the use of many types of aircraft, especially many high performance aircraft presently being used by the military.

The capability to meet the following requirements is used to select candidates for the low flying survey aircraft.

1. Operate with a payload of 2000 pounds plus a pilot, copilot, and one operator.
2. Contain sufficient usable space for installment of survey apparatus and data transmission equipment.
3. Provide 5 kva electrical power, preferably from engine generators.

4. Cruise between 150 and 350 knots at low altitude.
5. Be readily adaptable to equipment installations, both permanent and removable.
6. Operate at altitudes as low as 1000 feet with a maximum degree of flight safety.
7. Be maintainable at out of the way airports (safe distance from large cities and military installations).
8. Be stowable in existing hangars at remote airports.

It is assumed that only production aircraft are to be considered and that modification will be limited to that needed to install the equipment necessary for accomplishing the mission.

9.2 Aircraft Types and Characteristics

Using the above considerations as guidelines, candidate aircraft and selected characteristics are listed in Table 9.1.

It is noted that drones are not included in this list of candidate survey aircraft. This omission of drones is due to the fact that survey aircraft are restricted to operate in an air environment relatively free of radiation. Consequently, the crew is not subjected to excessive radiation which eliminates the primary reason for using more sophisticated, less reliable drones.

Table 9.1

AIRCRAFT PERFORMANCE

		No. of Seats (Payload)	Gross Wing Area	Weight Empty	Gross Weight	Maximum Speed 1000 Ft. Alt.		Maximum Range 1000 Ft. Alt.	
						Speed	Range	Speed	Range
Aerocommander 560F(L26)	RECP	1400 lbs	255	4,700	7,500	198	1,505	161	1,715
Beechcraft G18S(L23)	RECP	7–9	360	5,910	9,700	195	1,170	151	1,470
NAA T-39 Saberliner T3J	Turbojet	4–8	342.5	9,199	15,530	408	702	276	806
Grumman Gulfstream	Turbo-prop	10–14	615	21,100	35,100	329	1,228	311	1,383
Lockheed C140 Jetstar	Turbojet	2500 lbs	542	20,466	40,921	403	944	393	950
Howard 500	RECP	10–14		22,000	35,000	300	1,600	246	2,177

The cabin space listed for the Aerocommander 560F (see Table 9.2) includes a crew compartment for two. The remaining amount of space is not large enough for one additional crew member and the amount of data system equipment required. Thus, the Aero 560F is not considered further in the analysis. One possible installation on the Beech 18S is shown in Figure 2.1. However, a center of gravity analysis which is required before installation may introduce special installation problems requiring rearrangement of equipment. The cabin space and payload of the other candidate aircraft are sufficient for easy installation and maintenance. Movable installation mounts are possible in these larger aircraft. A cutaway of the Howard 500 is pictured in Figure 8.4 and of the Grumman Gulfstream in Figure 8.2.

Table 9.2

CABIN SPACE

	Length (Inches)	Width (Inches)	Height (Inches)
Aerocommander* (560F) L26	129.5	52	53
Beech 18S L23	125	52	66
NAA T-39 Saberliner	190	62.5	67.4
Grumman Gulfstream	396	88	73
Lockheed C-140 Jetstar	336	-	73
Howard 500	336	64	74

*A crew of two occupies part of this cabin space.

9.3 Estimates of Aircraft Cost

9.3.1 Investment Costs

The investment costs for the aircraft and engines were obtained from the manufacturer. These costs are qualified on the basis that they were prepared for 50 aircraft to be delivered in the spring of 1964.

The costs of the navigation system and the sensor equipment were estimated from component costs. The cost of equipment installation is based on past modification experience. These costs include modification engineering of equipment, installation engineering cost, and actual cost of installing the equipment in an aircraft already produced. Where it would be possible to install the special navigation equipment and sensor equipment in the aircraft while it is in production, the cost of actually installing the equipment could possibly be reduced to 40 to 60 percent. This savings could be from $16,000 to $24,000 per aircraft in the investment cost. However, the engineering costs for modification of equipment and installation would remain the same.

The above costs are itemized in Table 9.3.

9.3.2 Operating Costs

The operating costs for the aircraft in this comparison were computed by using the Air Transport Association standard method modified for the particular type of operation. The costs

Table 9.3

AIRCRAFT INITIAL INVESTMENT COST

Cost Categories	Sensor Vehicles				
	Beech G18S	Grumman 159	NAA T-39	Lockheed C-140	Howard 500
Investment					
Airplane with Standard Airborne Radio and Furnishings Cost	$119,715	$1,000,000	$603,000	$1,450,000	$591,000
Special Navigation Equipment Cost	97,000	97,000	97,000	97,000	97,000
Special Sensor Equipment	50,000	50,000	50,000	50,000	50,000
Cost Modification, Installation Eng. and Installation Mfg. Based on 50 Aircraft	70,000	70,000	70,000	70,000	70,000
Total Investment Cost per Aircraft	336,715	1,217,000	820,000	1,667,000	808,000

for this comparison are divided into two categories: (1) costs that vary directly with utilization, and (2) fixed costs.

The variable costs depict the flying operations in costs of fuel and oil. Other variable costs are maintenance labor and material costs. These costs include the direct labor based on average labor cost, plus a 12.5% cost for the maintenance burden, and the cost of material used in maintaining the aircraft and engines. The special equipment maintenance cost and the cost of landing fees are also included.

The fixed costs for operating the system include the air-crew salaries, and the hangar rental. It was assumed that aerial monitoring crews were Air Force Reserve personnel. The crew salaries were computed for a three man crew:

Pilot, Captain (10 years experience)

Copilot, Captain (8 years experience)

Systems Operation, Staff Sergeant (6 years experience)

These crews will have reserve duty 24 days a year (48 paid periods). It was also assumed that the aerial monitoring crews were attached to and co-located with Reserve Recovery units now assigned to non-military dispersed airports. Since a USAF officer and two airmen are scheduled to be permanently assigned to each dispersal base, it was assumed that these personnel and the recovery units would handle the duties of operational and administrative support for the aerial monitoring unit.

The recovery unit personnel at the dispersal base would be available for ground handling of the aerial monitoring aircraft during an emergency. Part of the recovery unit's training will be in conjunction with the peacetime operations of the aerial monitoring system.

Operating costs are itemized in Table 9.4.

Table 9.4

AIRCRAFT OPERATIONAL COST

	Beech G18S	Grumman 159	NAA T39	Lockheed C140	Howard 500
Operating Cost — $/Flight Hour					
Variable Costs					
Cost of Fuel	$22.40	$130.49	$180.72	$327.48	$108.65
Cost of Oil	.50	1.20	2.16	3.84	6.00
Sub—Total	22.90	131.69	182.88	331.32	114.65
Cost of Airplane Labor	8.57	16.90	14.82	16.42	
Cost of Airplane Material	4.46	10.93	7.15	13.94	
Sub—Total	13.03	27.83	21.97	30.36	30.00
Cost of Engine Labor	1.84	5.62	7.70	15.40	
Cost of Engine Material	3.66	11.42	12.26	24.53	
Sub—Total	5.50	17.04	19.96	39.93	12.30
Cost of Special Equipment Maintenance	3.50	3.50	3.50	3.50	3.50
Landing Fees	1.00	1.00	1.00	1.00	1.00
Total Variable Costs	45.93	181.06	229.31	406.11	161.45
Fixed Costs — $/Year					
Crew Salaries	2610.06	2610.06	2610.06	2610.06	2610.06
Hangar Rental	2528.93	7183.87	2803.54	4731.55	5861.14
Operational and Administrative Support	0	0	0	0	0
Total Fixed Cost	5138.99	9793.93	5362.42	7341.61	8471.20

10. PERFORMANCE EVALUATION

This section presents effectiveness comparisons between various candidate systems where range and speed of the survey aircraft and total system costs are the primary factors in the evaluation. The capability to make a uniform survey of the U.S. is used as a basis for the quantitative computations for comparing the various monitoring systems.

Even though the National Center needs to have a uniform degree of accuracy or detail of radiological information over the entire country, it does not necessarily require the capability to make a uniform survey over the U.S. In portions of the country, especially in the southwest and western U.S., where there are only a few logical strategic targets, a more economical system might suffice. A widely spaced survey with separation distance up to 150 to 200 miles can be made to search for fallout areas. This search may be followed by a detailed survey of the fallout areas discovered.

However, it is concluded from the results presented in Section 5 that a system which is best for a uniform survey would also be best for variations from it where only a portion of the country may be surveyed in fine detail.

10.1 Cost Effectiveness

The cost which enters in the decision procedure consists of the initial investment in equipment including installation costs and an operating cost for a period of five years. These costs and the assumptions for their derivation are detailed in Section 9. The number of survey aircraft of each type required to make the survey was computed by combining a map exercise with the mathematical models described in Section 5.

It is convenient to group the various monitoring systems studied into two general classes, the Covey system and the Flock system.

The Flock system is used to designate the group of survey aircraft operating independently of each other. (No control aircraft.) Each Flock aircraft has a data collecting, data processing and air-to-ground data transmission system.

The Covey system consists of a mother aircraft flying at 20,000 feet altitude receiving data from several sensor carrying aircraft flying at low altitude. The control aircraft receives data from the survey aircraft, processes it into a format compatible with the data transmission system and transmits the composite data to the ground by long range radio. The air-to-air communications system between the survey aircraft and the director aircraft is line of sight and limits the separation distance to no more than 250 nautical miles.

10.1.1 Flock System

The number of each type of aircraft required to make the survey of the U.S. using survey Method B is shown in Figure 10-1.

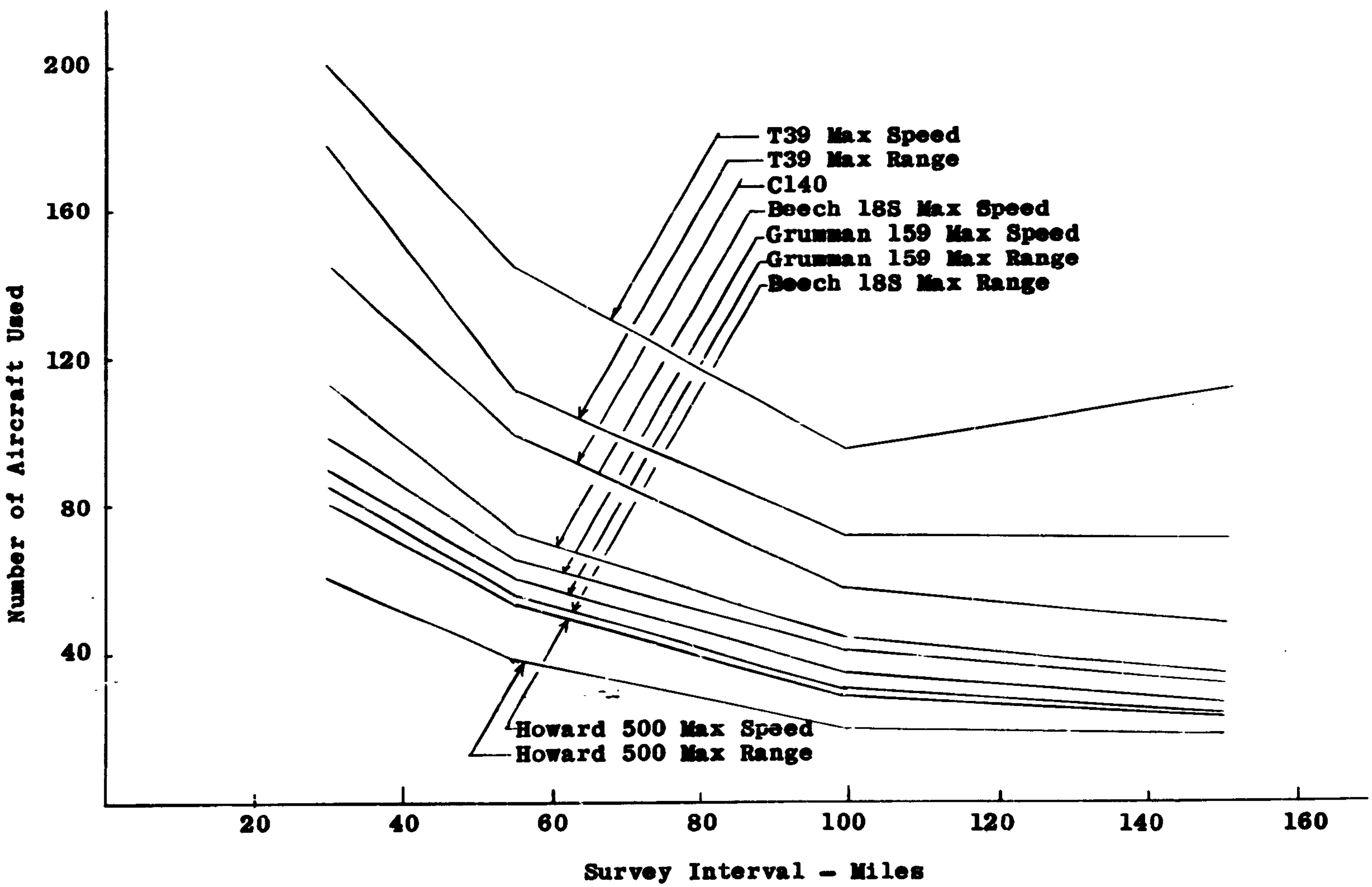


Fig. 10.1 Number of Survey Aircraft vs Fineness of Survey

The number of bases for each type is half the number of aircraft. With the exception of the C-140, two speed-range combinations determined by maximum speed and maximum range speed at low altitude are associated with each aircraft.

These curves reflect the effect of aircraft range on survey separation distance. The curve for the C-140 begins to increase for flight separation distance greater than 100 miles because too much of its range is used in the east-west direction rather than in the north-south direction. For the same reason the other curves will turn upward at some separation distance greater than that shown.

The curves in Figure 10.1 show that the number of aircraft required to make a survey of the U.S. is proportional to the range. The Howard 500 can make the survey with the least number of aircraft and the North American T39 requires the largest number. There is an appreciable difference between the number of aircraft required at maximum range and maximum speed flights in all cases.

The total system cost for each type of aircraft is shown in Figure 10.2 for a 50-mile survey interval. Costs range from slightly more than 20 million for the Beech 18S at maximum range speed to over 180 million for the high speed Lockheed C-140. The survey time varies from 9.5 hours for the Beech 18S to 1.7 hours for the North American T39. Although it requires a smaller

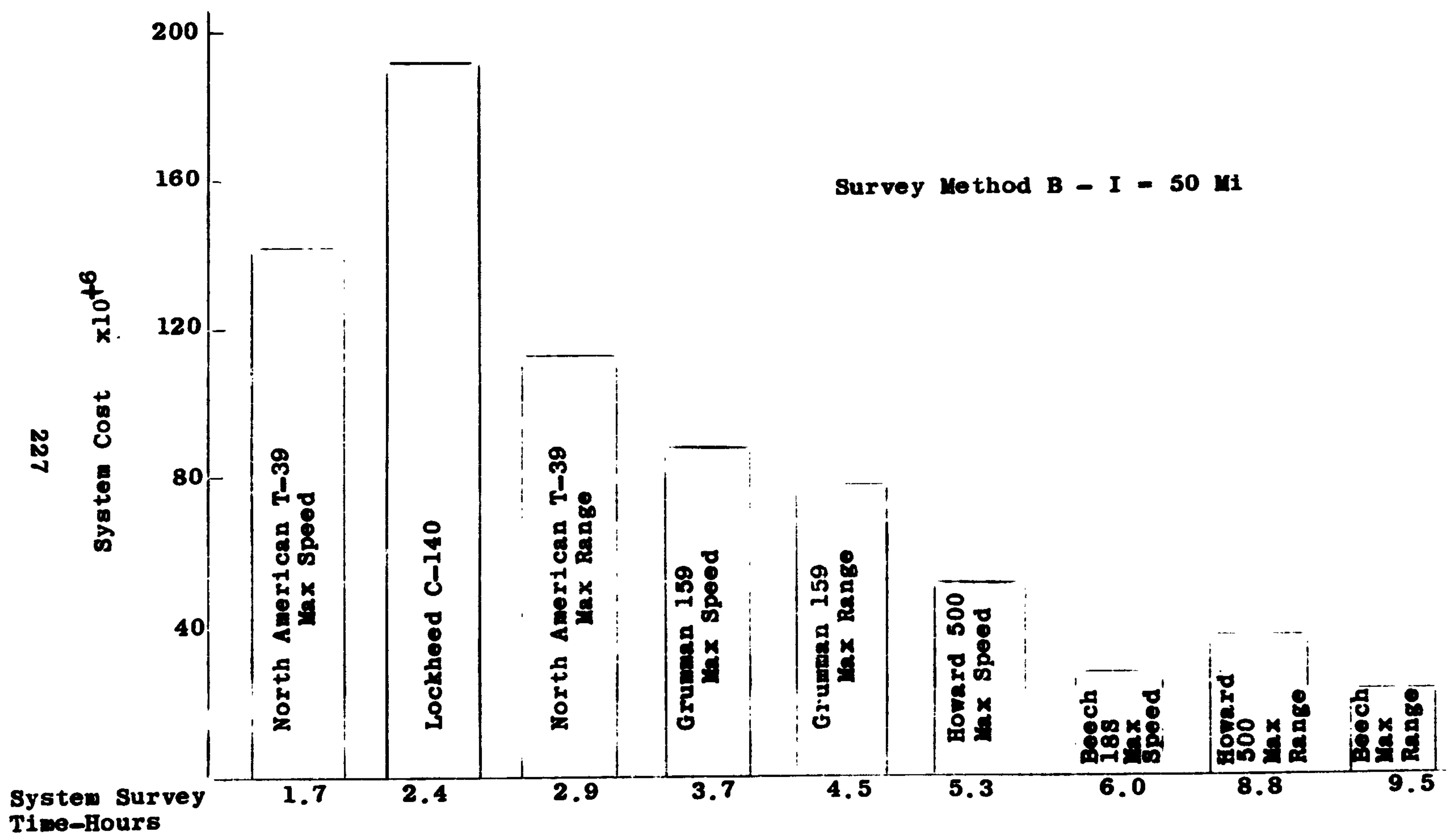


Fig. 10.2 Monitor System Cost Comparison, I = 50 Mi

number of Howard 500 aircraft to make the survey, the system cost of the Beech 18S is less. At maximum range speed the system cost using the Howard 500 is almost twice that of the Beech 18S and that of the Grumman is slightly less than 4 times the cost of the Beech 18S. On the other hand, the survey time of the Grumman is less than half that of the Beech 18S. There is less than one hour difference between the Howard 500 and the Beech 18S.

A comparison of systems costs as a function of survey interval is given in Figure 10.3. The curves show that a decision preference between systems based on cost does not change with the survey interval except for the Lockheed C-140 at a survey interval of 140 miles.

The system costs given in Figure 10.2 for survey Method B are compared with the system costs for survey Method A in Figure 10.4. They are ordered according to survey time. The costs for survey Method A were computed using a 500-mile length of the survey rectangle and a survey interval of 50 miles.

It is recalled that in survey Method A only one aircraft is located at each base and a take-off base becomes the landing base for an adjacent aircraft in the survey chain. Method A is compared with Method B in the form of the ratio of the cost using Method A to that using Method B. The value of the ratio A/B shown at the bottom of Figure 10.4 shows this comparison quantitatively. It is seen that for each system it is less

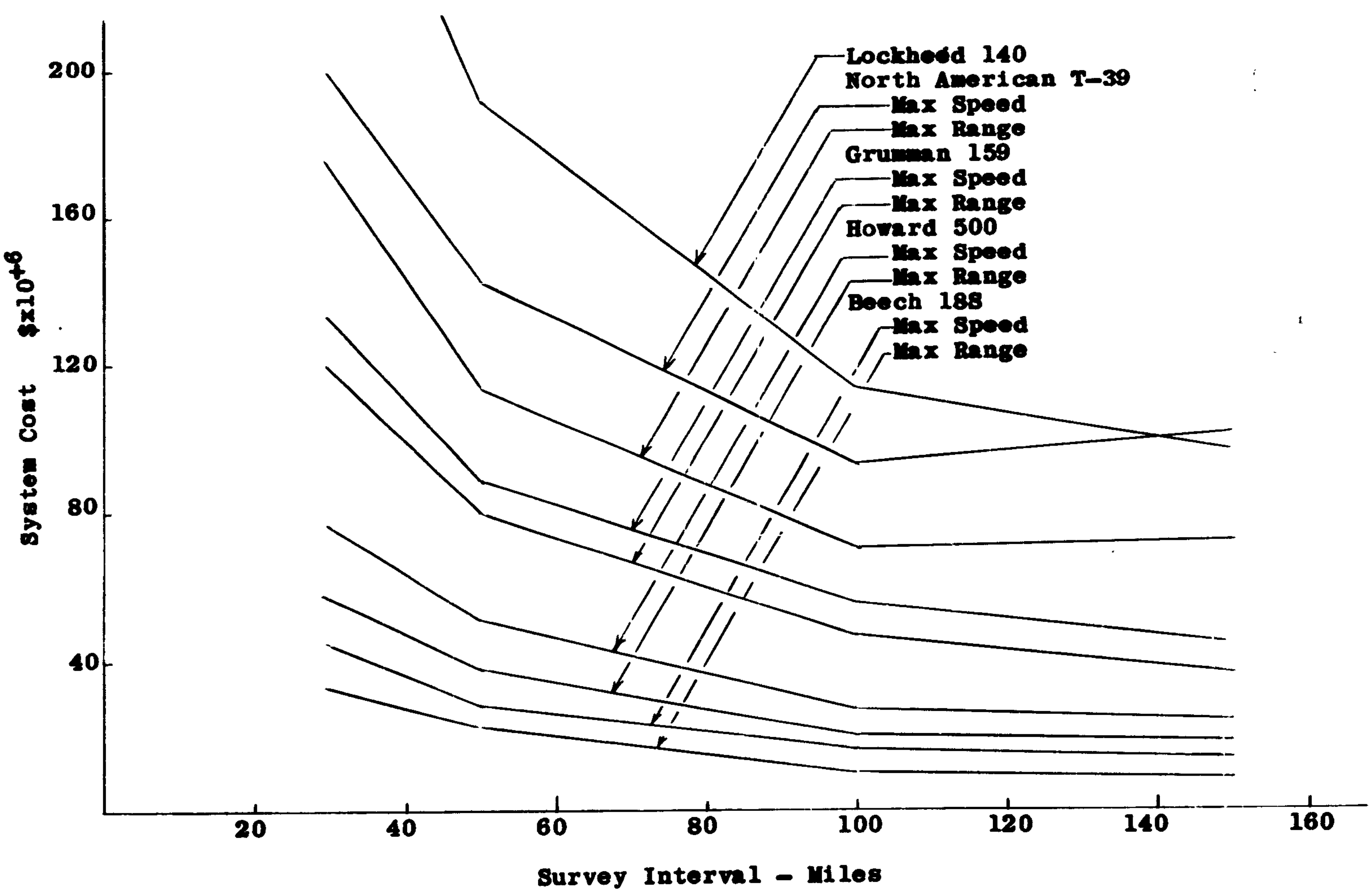


Fig. 10.3 Comparison of System Costs

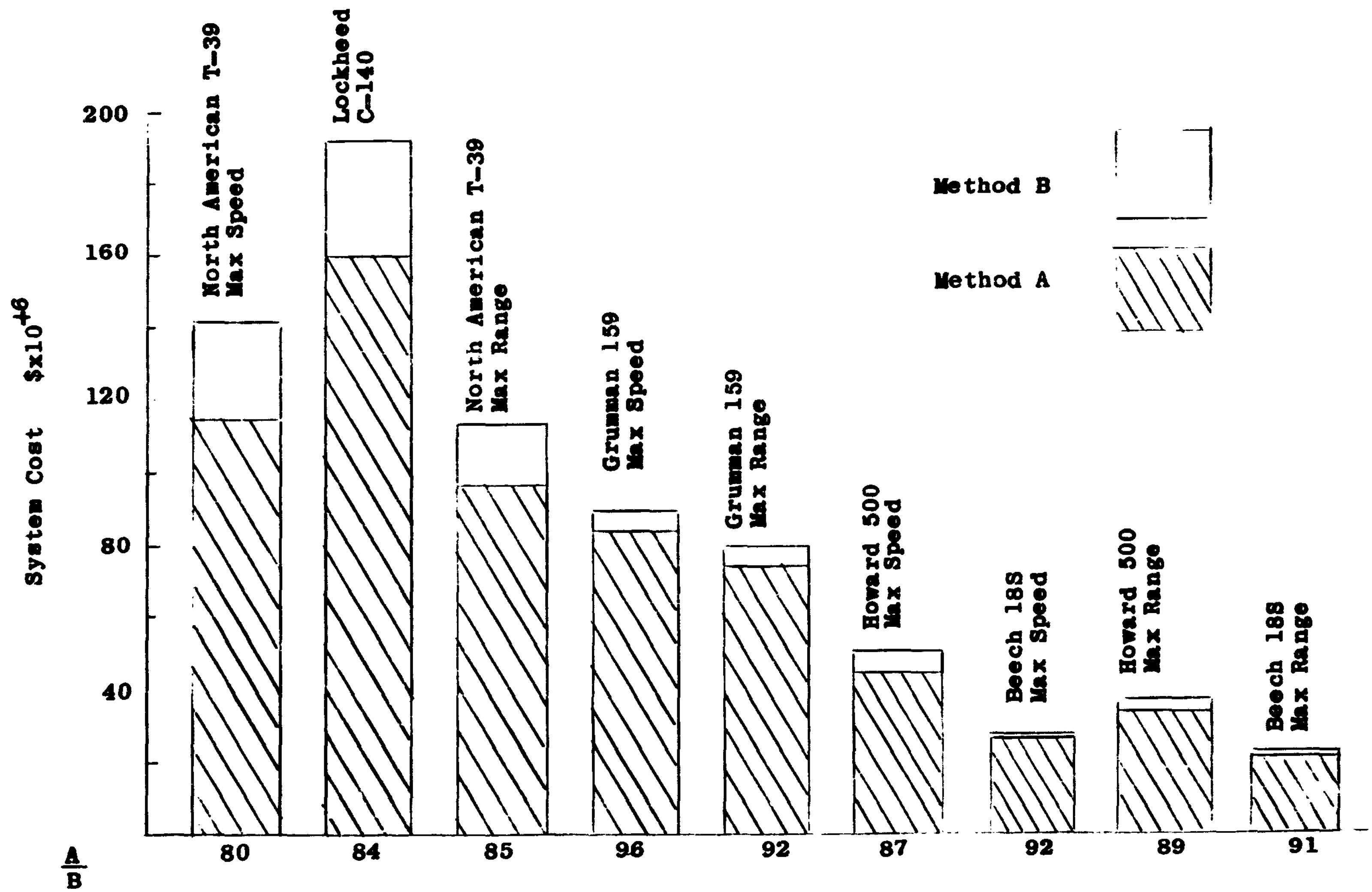


Fig. 10.4 Comparison Between Survey Method A and Method B

expensive to use survey Method A than to use survey Method B. The rank of the systems according to total cost is the same for both methods. This is true for making any survey of equal areas.

Although Method A is on the order of 10% less costly than Method B (fewer aircraft are required), Method B has several important advantages over Method A. In a system designed to use Method B, each aircraft or pair of aircraft is assigned to survey a particular rectangular area. The dimensions of this area are determined on the basis that the fallout cloud passage is from w[illegible] to east. However, if the wind is different from this at the time the survey is to be made, each aircraft can use an alternate survey pattern over his area without having to coordinate his method with all other aircraft in the system. It is recalled (Fig. 5.4) that areas are not associated with each aircraft in Method A. The above argument combined with the discussion in relation to Figure 5.4 leads to the selection of Method B upon which to design the monitoring system.

10.1.2 <u>Covey System</u>

The area of control of the director aircraft in the Covey system is limited to a rectangle whose width extends 250 miles on either side of the line of flight of the director aircraft. The length of the rectangle is equal either to the range of the aircraft or to half its range, according as Survey Method A or Method B is used.

If Method A is used, a complete covey unit must be based at either the north or south end of the rectangle assigned to it and, after completing the survey, must land at the opposite end. The number of survey aircraft per director aircraft is N = W/I. If Method B is used, the rectangle length is approximately half the range of the aircraft and the number of aircraft per covey is N = W/2I. It is not economical with either method for the entire covey to be based at one base. Too much useful range is lost in going to and returning from the survey areas farthest from the base.

Using the Howard 500 or the Grumman Gulfstream as the Director aircraft and the Beech 18S for the survey aircraft, 10 coveys of 5 survey aircraft each are required to monitor the U.S. with a survey interval of 50 miles where the flight procedure is based on an up and back flight for each survey aircraft. Five coveys with 10 aircraft each are needed for a one-way flight (Method A). It is estimated that the Director aircraft would not receive and process data from more than 10 survey aircraft.

The estimated cost for a Covey system using the Howard 500 and the Grumman Gulfstream for the Director aircraft is given in Table 10.1.

Table 10.1

TOTAL SYSTEM COST* FOR COVEY SYSTEM (I=50)

	Howard 500		Grumman Gulfstream	
	One Way Flight	Up and Back Flight	One Way Flight	Up and Back Flight
Director A/C	5,596	11,192	7,683	15,366
Survey A/C	18,750	18,750	18,750	18,750
Ground Data System	76	76	76	76
TOTAL	24,422	30,018	26,509	34,192

*Cost in Thousands of Dollars

10.2 Response Time

Response time is defined as the elapsed time required to sense, transmit, and process the data, including the time to construct the final presentation map. Response time can vary with the endurance of the aircraft, which is a function of speed and range, as well as the type of data transmission and data presentation used. Increasing the number of survey aircraft, where each does not use its full range capability (operating at less than its endurance), will shorten the data collection time, provided it does not overload the data transmission and processing equipment. According to this definition, response time does not include the time from the first burst until the survey begins (time for fallout to come down).

The time required for data collection shown in Figure 10.2 represents the endurance of the aircraft at the given aircraft speed and is the same for survey Methods A and B. It is seen that decreasing the response time by using high performance aircraft is expensive in total cost. The survey time for the Beech 18S at maximum speed is 6.0 hours and at maximum-range speed is 9.5 hours. The survey can be completed in 1.7 hours with the T-39 for an increase in cost by a factor of about 7.

It was remarked earlier that the data collection time could be lessened by employing more aircraft in the system and not utilizing the full endurance (range) of the aircraft. In Figure 10.5 the smaller survey times for the Beech 18S and Howard 500 have been obtained by doubling the number of aircraft in the monitoring system. The number of aircraft can be doubled by placing four aircraft at each base in survey Method B, and allowing each to survey one-half of the area or roughly along one-half of the assigned flight path.

Likewise, the cost of the survey system can be approximately halved by performing one ground refueling, thus, doubling the survey range of an aircraft. This would approximately double the data collection time, halve the number of aircraft required, and keep the same number of bases; approximately half would be refueling bases. The number of units in the ground data system would be decreased, since the rate at which data are collected would be less.

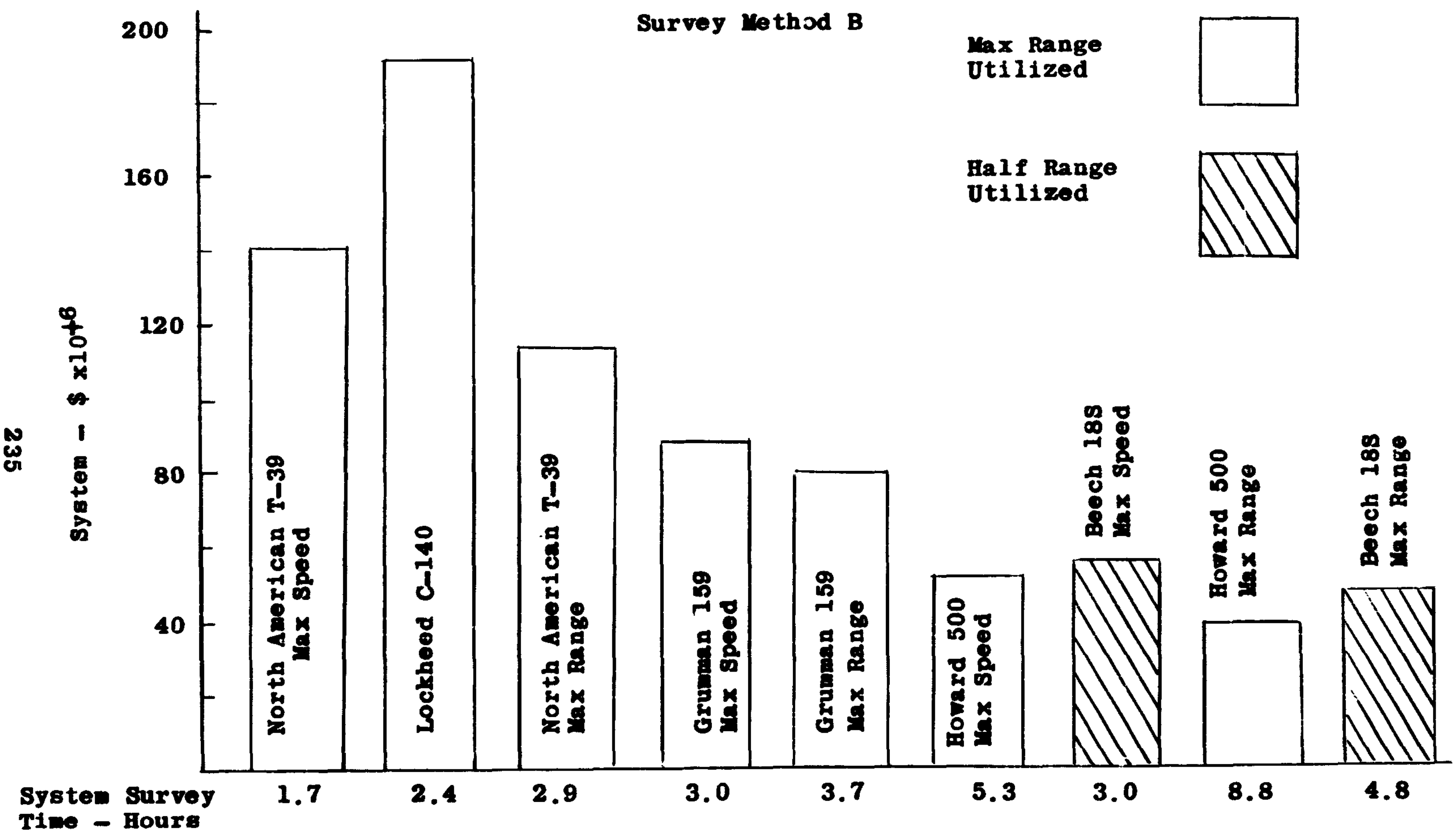


Fig. 10.5 Effect of Response Time on System Cost

Estimates of the total response time shown in Table 10.2 are found by adding to the data collecting time (aircraft endurance) an estimate of the time required after the survey flights are finished to process and transmit the data. The latter estimates are made in Section 8.

The response times range from 5.1 hours to 16.7 hours. The time for the low speed, long range Beech 18S with a digital system is longest and that for the high speed Lockheed C-140 with the facsimile system is least. It is recalled (Fig. 10.1) that the cost of the high speed C-140 system is over nine times the cost of the Beech system.

Not all of the difference in response time is the result of the difference in aircraft endurance; there is an appreciable difference in time between transmission and processing methods. The facsimile system requires the shortest time and the digital requires the longest. It is important to note the effect of survey time on the time required for processing. With the digital system, 7.2 hours are added to the survey time of the Beech 18S system, while 11.2 hours are added to the higher speed systems. There is no significant variation with speed for the facsimile and teletype systems and no variation for the digital limiting system.

Table 10.2

COMPARISON OF RESPONSE TIMES

Aircraft Type		Facsimile (Hrs)	Teletype (Hrs)	Digital (Hrs)	Digital Limiting (Hrs)
Beech G18S	Survey Time	9.5	9.5	9.5	9.5
	Process Time	2.9	3.9	7.2	5.2
	Total	12.4	13.4	16.7	14.7
Howard 500	Survey Time	8.8	8.8	8.8	8.8
	Process Time	2.9	3.9	7.2	5.2
	Total	11.7	12.4	16.0	14.0
Grumman Gulfstream	Survey Time	4.5	4.5	4.5	4.5
	Process Time	2.7	3.7	11.2	5.2
	Total	7.2	8.2	15.7	9.7
North American T-39	Survey Time	2.9	2.9	2.9	2.9
	Process Time	2.7	3.7	11.2	5.2
	Total	5.6	6.6	14.1	8.1
Lockheed C-140	Survey Time	2.4	2.4	2.4	2.4
	Process Time	2.7	3.7	11.2	5.2
	Total	5.1	6.1	13.6	7.6
Covey System 10 Direc- tors 50 Beech G18S Survey	Survey Time	9.5	9.5	9.5	9.5
	Process Time	1.7	3.0	5.2	4.2
	Total	11.2	12.5	14.7	13.7

The response time for the Covey system using the Beech 18S as a survey aircraft is less than the time for the Flock system with the same aircraft. This decrease in response time amounts to one hour for the facsimile and digital limiting systems and two hours for the digital.

10.3 System Accuracy

The radiation contours are intended to present to the user a picture of the radiation situation as interpreted by the monitoring system. The reliance that can placed on these contours depends upon the fineness with which the survey is made and on the accuracy of the data that are collected and recorded.

The fineness of the survey is defined by a combination of the radiation levels chosen for measurement and the separation of the flight paths along which the measurements are made. These two factors are somewhat interdependent. For example, if the 300 R/hr is specified, only enough cuts are required to intercept the 300 R/hr line and additional cuts made between the 300 R/hr line and the 100 R/hr line do not contribute much to the accuracy of the final result.

The accuracy of the presented data can be defined by the probability that the highest R/hr line of interest is intercepted by a survey flight. The expected values of the hot line for an idealized fallout pattern are used to compute the probabilities given in Figures 10.6 and 10.7. These probabilities can be interpreted to mean the expected percent of the time that a survey of a fallout area will provide a dose rate reading of the magnitude specified. Probability numbers given in Table 10.3 for 30 miles and 50 miles survey flight separations are taken from these figures.

Table 10.3

PROBABILITIES ASSOCIATED WITH 30 MILE AND 50 MILE SEPARATION FLIGHTS

	1 MT				5 MT			
	15 mph		30 mph		15 mph		30 mph	
R/hr	100	300	100	300	100	300	100	300
30 miles	.64	.44	.92	.66	1.0	.94	1.0	1.0
50 miles	.40	.10	.58	.40	1.0	.60	1.0	1.0

The data in Table 10.3 show that the amount of detail relative to 100 R/hr and 300 R/hr dose rates is not significantly better from a 30-mile survey than from a 50-mile survey for 5 MT bursts. For 1 MT bursts, the probability numbers increase by as much as 50% although the largest for the 30-mile survey is only 92%. The difference in cost to provide the extra survey aircraft and equipment to obtain maximum detail is appreciable. Using data in Section 10.1, it is found that, depending on the aircraft used, the cost of making a uniform

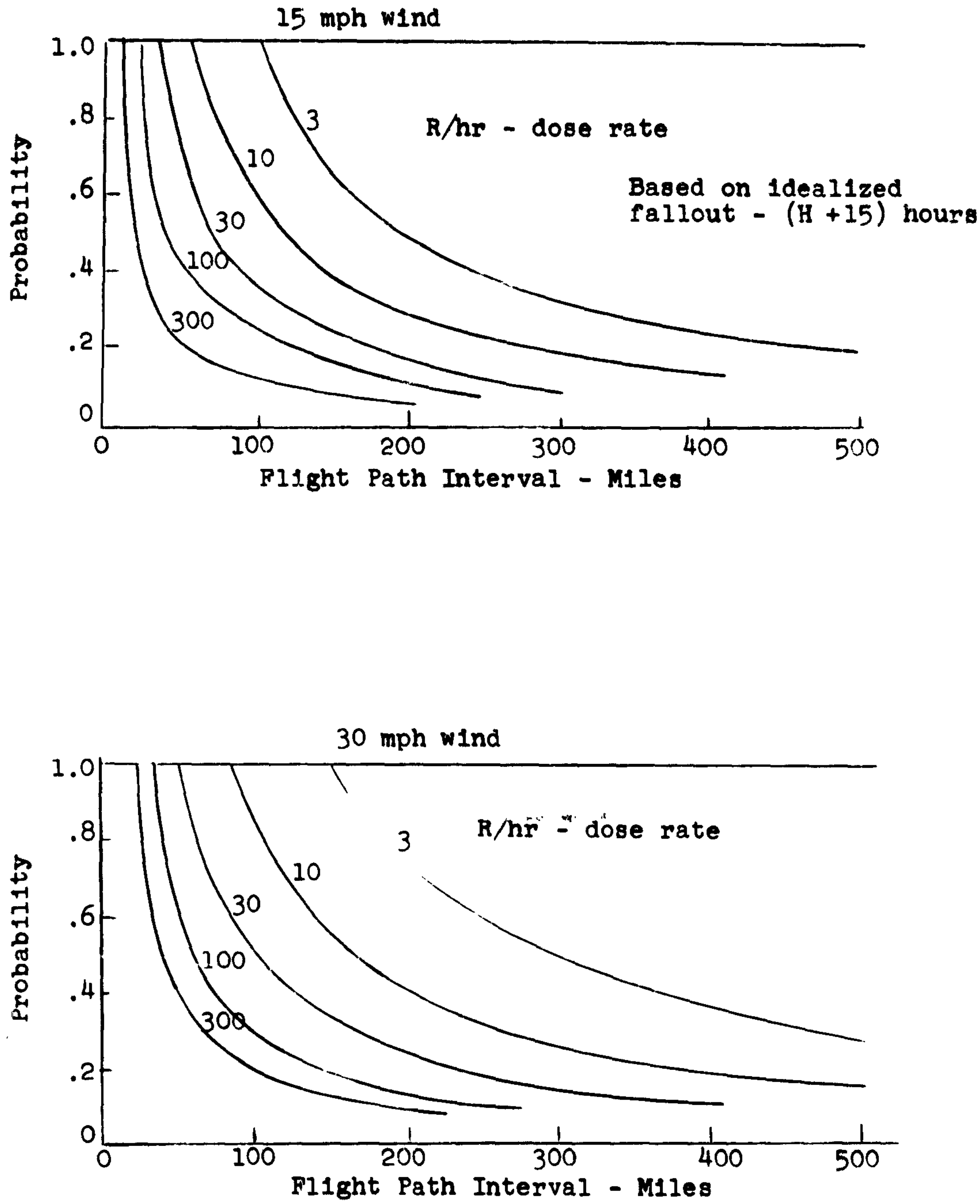
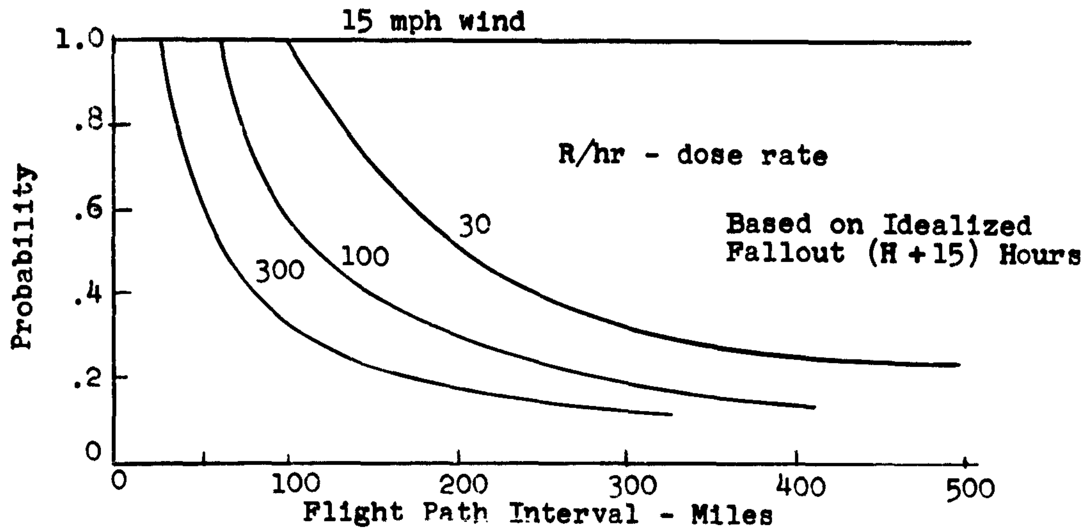


Fig. 10.6 Probability of Intercepting Isodose Rate Lines - 1 Mt



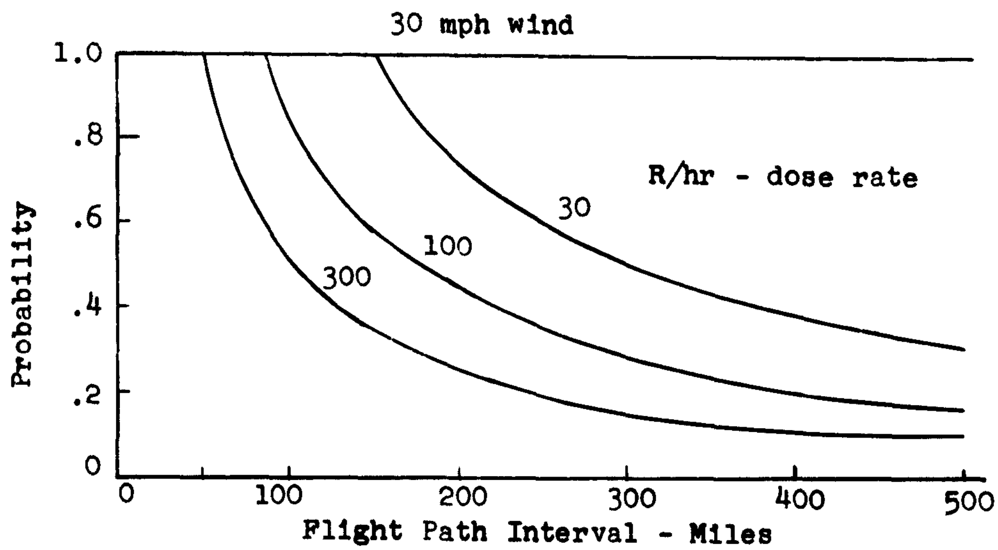


Fig. 10.7 Probability of Intercepting Isodose Rate Lines - 5 Mt

survey of the U.S. with a 50-mile spacing is from 30% to 35% less than one with a 30-mile spacing.

Two sources of error contribute to the inaccuracy of the data collected and recorded. There are errors associated with estimating the intensity of the radiation on the ground at some reference time from measurements taken in the air. The magnitude of these errors are a combination of errors from sensor design, errors resulting from estimating radiation attenuation with altitude, and errors in time scaling to account for decay rate. A second source of error derives from the inaccuracy of the ground position at which each reading is made.

The accuracy of the Litton LN-3 inertial navigation system is estimated to be on the order of 2 n.mi. per hour at a 300-knot speed. This is the error that is accumulated from the point of the last position fix point. It is estimated also that visual fix points which can be used to erase a large part of the accumulated errors are available at least each 300 miles along any pre-planned flight path. Based upon this assumption, it is expected that position errors during the survey flight will not exceed a CEP of 3 to 4 miles.

The effect of these errors is discussed in relation to the survey flight paths shown in Figure 5.11. It can be seen that an error in the distance between successive flight paths (lateral range error) will have only a small effect on the value of the contours because of the small gradient of the dose rate in the downwind direction. The errors associated with an inertial guidance system are random with respect to both range and azimuth. The random lateral errors may cause the readings to be taken on either side of the intended flight path. However, a series of readings over a single fallout area (5 to 30 minutes of flight) will fall on one side or the other of the intended path, so that each set of points collected along a cross flight of a fallout area are subjected to the same error.

The effect of range errors may tend to make the contours vary somewhat from a smooth idealized fallout pattern or accentuate the irregularity of an actual burst. The relative error between the position of successive points along a flight path (range error) across a single fallout area is small because of the short distance between the points being recorded. If there is an appreciable distance (time) between recording points on flight path 1 and on flight path 2 (Fig. 5.11) over the same fallout area, the effect of range errors is to displace the entire set of readings in range, either forward or backward. The relationship between the location of points on flight path 2 and 3 may be similar. The net result would be to deform the relatively smooth contours into wavy lines or to displace a portion of the fallout area if the errors are biased in the same direction.

A relationship between range error and the change in dose rate along cross wind flight paths is found by assuming that the cross section of a fallout pattern in the cross wind direction can be approximated by the expression

$$R(y) = C\, e^{-\frac{y^2}{\sigma^2}}$$

where C is determined by the value of the hot line, and σ describes the distribution of fallout about the hot line. A change dR in R caused by an error dy in the down range position of the measurement is given approximately by

$$dR = -\frac{2y}{\sigma^2}\, C\, e^{-\frac{y^2}{\sigma^2}}\, dy$$

and the percent change in R is

$$\left|\frac{dR}{R}\right| = \frac{2y}{\sigma^2}\, dy\ .$$

if $\bar{y}$ is the position of the 1R/hr. line then

$$\bar{y} = \sigma\sqrt{\ln C}$$

$$\left.\frac{dR}{R}\right]_{R=1} = \frac{2\sqrt{\ln C}}{\sigma}\, dy.$$

For idealized fallout patterns resulting from the explosion of megaton weapons, $\bar{y} \geq 20$ miles, and $\sigma \geq \frac{20}{\sqrt{\ln C}}$

Therefore

$$\left.\frac{dR}{R}\right]_{R=1} \leq \frac{\ln C}{10} \quad dy.$$

For most cases of interest (when fallout is down), C < 1000 R/hr. and

$$\left.\frac{dR}{R}\right|_{R=1} \leq \frac{\ln 1000}{10} \quad dy = .69\ dy.$$

The last equation shows that the percent error in the 1 R/hr. reading is no greater than 69% of the magnitude of the error in y.

10.4 Rate of Decay of Nuclear Fallout

10.4.1 Time Scaling for Simultaneous Bursts

After a nuclear burst takes place, decay of the radioactive material starts immediately. Samples taken in an area by a single aircraft cannot all be made at the same time; so as the aircraft moves from one sample point to another, decay of the fallout is still taking place. Thus, it becomes desirable to have a reference time to which all the sample times can be referred. This is accomplished by taking a sample reading at some point, and scaling the value to some reference time using the decay function $t^{-1.2}$. The most common reference time is

H + 1 hours, however, some reference time after the readings are taken may be more convenient.

For a single burst, reasonably accurate predictions of the radiation level at a given location at time t can be made by either of two methods: (1) if the time of burst is known, a single measurement of the dose rate can be taken at some known time after the burst, or (2) if the time of burst is not known a second measurement of the dose rate at the same point can be taken after a given interval of time. In the "Effects of nuclear Weapons" it is shown that the function $t^{-1.2}$ approximately describes the decay of radiation from a single source. Consequently the following scaling law can be applied to both cases:

$$R(t) = C\,(t-H_1)^{-1.2}$$

Where H_1 is the time of burst, R is the dose rate in R/hr at time t, C is an arbitrary constant and $t > H_1$.

For the first case, if $t = t_o$ is the time the measurement is taken, $R(t_o)$ is the measured dose rate, and H_1 is known, C can be computed to give

$$R(t) = R(t_o)\,(t_o-H_1)^{1.2}\,(t-H_1)^{-1.2}$$

A similar result can be obtained for the second case by solving two simultaneous equations where C and H_1 are the unknowns.

10.4.2 Approximation to Decay of Residual Activity With Different Ages

For bursts which take place at the same time, if the fallout from one burst mixes with that from another burst, then the dose-rates are additive and the decay function is exponential and approximately follows the $t^{-1.2}$ decay factor. However, if the bursts do not take place at the same time, then the dose-rate is additive at each point but the decay function for the sum is not exponential. It is desirable to have a function which approximates the rate of decay for fallout from bursts which occur at different times where the number and the yield may be unknown quantities.

It is assumed that the time, H_1, of the first burst is known and the time, H_2, of the last burst is known ($H_2 > H_1$). It is also assumed that at some point, a reading, R_s, is made at time t_o. Suppose that n bursts take place in the time interval H_1, H_2, Let $R(t)$ denote the actual dose rate of the fallout from these bursts at any time t. Then one approximation of $R(t)$ is found by assuming that the radiation level R_s measured at t_o resulted from a single burst at H_1. The approximation is denoted by $R_1(t)$ in Figure 10.8.

Another approximation is found by assuming that R_s resulted from a single burst at H_2. This function is denoted in Figure 10.8 by R_2. It can be shown mathematically that $R_1(t) < R(t) < R_2(t)$ for $H_2 < t < t_o$ and $R_1(t) > R(t) > R_2(t)$ for $t > t_o$ as shown in Figure 10.8 by the following method.

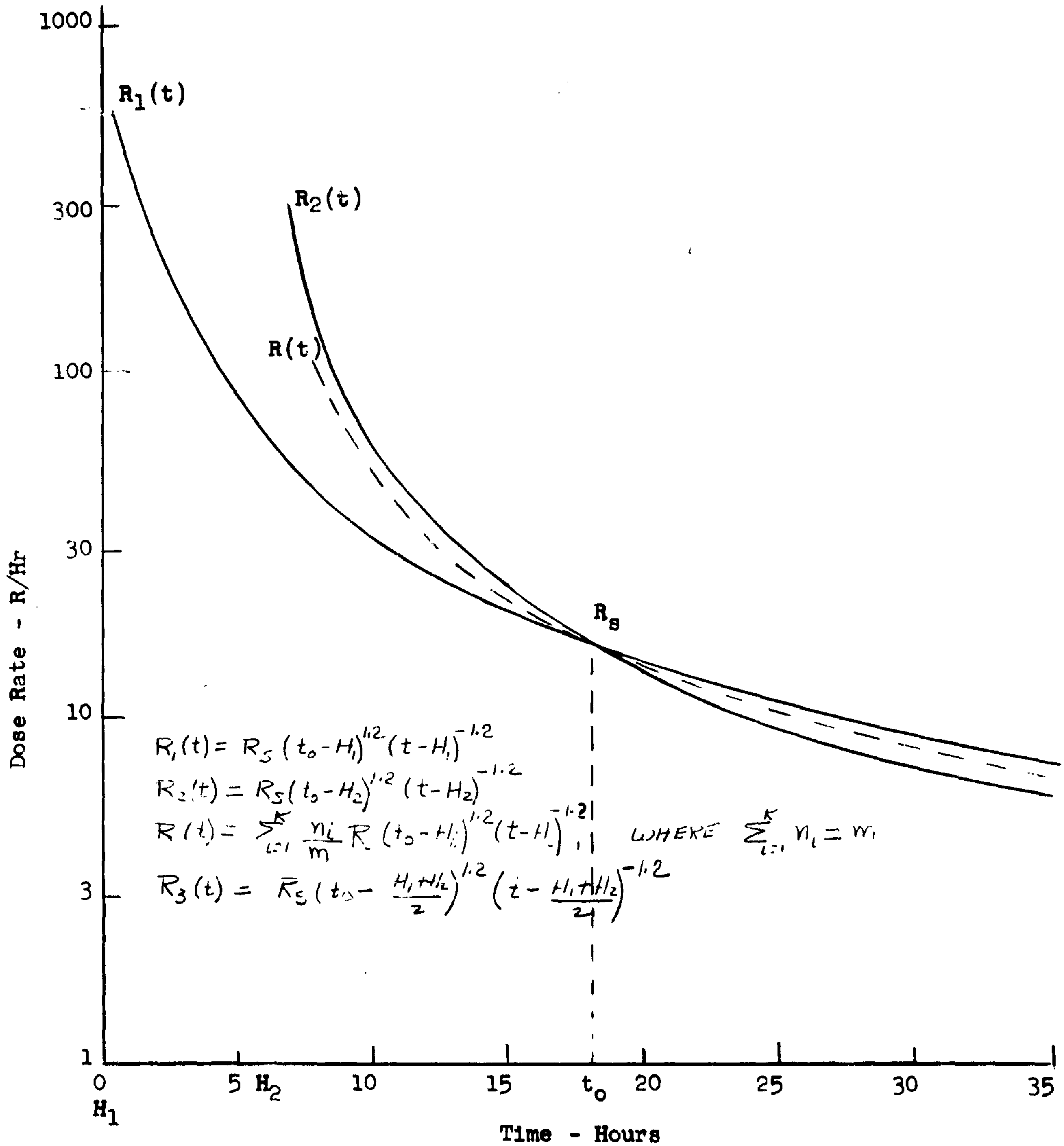


Fig. 10.8 Decay Rate Scaling Approximation

$$\frac{R(t)}{R_1(t)} < 1 \quad \text{for} \quad H_2 < t < t_o$$

$$\frac{R(t)}{R_2(t)} > 1 \quad \text{for} \quad H_2 < t < t_o$$

$$\frac{R(t)}{R_1(t)} < 1 \quad \text{for} \quad t > t_o$$

$$\frac{R(t)}{R_2(t)} > 1 \quad \text{for} \quad t > t_o$$

$R_1(t) = R(t) = R_2(t)$ for $t = t_o$

It can be argued that for time $t > t_o$, R_2 is a better approximation to R than R_1; and R_2 becomes a better approximation as the time interval H_2-H_1 increases.

A more versatile approximation, however, is found by assuming that R_s resulted from a single burst at time $t = \frac{H_1 + H_2}{2}$. This function is denoted in Figure 10.8 by R_3, and is given by the formula

$$R_3(t) = R_s \left(t_o - \frac{H_1+H_2}{2}\right)^{1.2} \left(t - \frac{H_1+H_2}{2}\right)^{-1.2}$$

By using the same method as above, it can be shown that R_3 is also bounded by R_1 and R_2; that is; $R_2 < R_3 < R_1$ for $t > t_o$.

The difference between the boundary functions, $R_1(t) - R_2(t)$, has a maximum value for some $t > t_o$. This maximum value and the time $t = t_m$ at which it occurs can be computed by equating to zero the derivative of the function with respect to t, and solving for t. This calculation gives:

$$t_m = \frac{H_2(t_o-H_1)^{.55} - H_1(t_o-H_2)^{.55}}{(t_o-H_1)^{.55} - (t_o-H_2)^{.55}}$$

and

$$R_1(t) - R_2(t)\Big]_{max} = \frac{R_s(t_m-t_o)(H_2-H_1)}{(t_m-H_1)(t_m-H_2)} .$$

11. CONCLUSIONS, RECOMMENDATIONS, AND IMPLEMENTATION PROGRAM

11.1 Conclusions

The design of an aerial monitoring system for making radiological surveys on a national scale is technically feasible and operationally practical. The subsystems can be instrumented from commercially available components and available aircraft require only installation of special equipment. The radiation sensor and electronics channel designs are within the state-of-the-art. Using a sodium iodide scintillation detector and logarithmic computers, the dose rate at ground level can be determined from simultaneous measurements of signal and background at altitude. The system is designed to register ground dose rates ranging from 1 R/hr to 1000 R/hr.

The design of the data system which includes equipment to process and transmit the data to Civil Defense Regional Centers utilizes proven components which are commercially available or can be fabricated from available parts. The data system capacity exceeds the maximum requirements assumed for the user.

A rectangular flight procedure whose primary data collecting flight paths cross the hot line (direction of fallout cloud passage) at right angles gives the largest number of data points per flight mile. Continuous dose rate readings from 1 R/hr to

1000 R/hr are recorded on tape, but discrete intervals are reported to the Regional Centers.

11.2 Recommendations

The Flock System with the Beech 18S as the survey aircraft and with facsimile data transmission is recommended as the preferred system (Secion 2.0) based on cost and response time. The Covey System with digital data limiting is second choice based on the desirability of automation.

Because contracts presently held by RCA and E.G. and G. are concerned with different systems to perform much the same task as the present contract, it is recommended that comparative analysis should be made during the design phase to determine areas of compatibility between the aerial monitoring system recommended in this report and a corresponding automatic ground based system similar to that being described by Radio Corporation of America.

A brief comparison can be made at this time. The aerial system can be designed to report radiation levels at fixed intervals of time along flight paths with a given spacing, or, as recommended in this report, it can be designed to report the geographical position where preselected radiation levels occur. On the other hand, a ground based system reports readings which occur only at preselected positions (sensor locations) determined long before the burst occurs. With the aerial system, the flight path can be varied to suit the fallout conditions and repeat surveys can be made to fill in gaps omitted in a previous survey. The ground based system may, depending upon the burst point, not record the critical radiation levels in an area unless the monitoring points are very close together. A ground based system can make reports immediately following nuclear explosions, while the aerial system must delay until the early fallout is essentially down.

Consequently, these two systems have characteristics which may be mutually beneficial for a composite system and a basic, valuable compatibility might be developed between them. For example, if the ground based system is designed with a 50-mile spacing, the airborne system could plan flight paths to overfly the ground sensors, supplying data at in-between points. A major problem area in this regard is the calibration of an airborne detector system and a ground sensor to give essentially equal readings at a point.

At the present time, data from the aerial system (a facsimile of contour lines) and the ground system (a numbered grid) are not presented in a common format until the national level is reached. Some consideration might be given to placing these in a common format at the regional level. As a beginning, both systems could report the same radiation levels, for example - 1, 3, 10, 30, 100, 300, 1000 R/hr, or a similar set.

11.3 Implementation Program

Here is presented a brief program of future work leading to the establishment of an aerial monitoring system.

Phase I - This is a low cost, experimental effort to determine those essential performance figures for the detector design which were not calculable under the present study. The deleterious effects of air-scattered radiation on the proposed two-detector configuration should be determined by flying over a fuel element source. At the same time, it would be economical to calibrate the detector and determine the constants of the equation for the altitude correction computer (Section 8.6.9). Also, more comprehensive data on contamination of air and vehicle resulting from airborne delayed fallout should be obtained to enable more accurate assessment of the radiation background.

At the successful completion of this phase, the Office of Civil Defense would know that the proposed system was technically sound.

Phase II - This would be a low cost development of the new items of hardware needed for a flight system. These items are considered to be well within the state-of-the-art. The major items would be:

o <u>Analog Computer</u> - The analog computer described in Section 8.6.9 should be designed and evaluated.

o <u>Dual-differential detectors</u> - the prototype system should be built, with electronics, power supplies, and standardization sources.

o <u>Data display</u> - The synchro repeaters providing coarse, medium, and fine latitude and longitude data to the strip charts should be evaluated to determine if this is the best method of displaying the data.

o <u>Foil covered ports</u> - The proposed ports with the motor driven foil covering for the detector to "look" through should be evaluated.

<u>Phase III</u> - A prototype survey aircraft should be instrumented and tested. The complete data system, navigation system, altimeter, radiation detection system and data transmission system should be installed. Generators for additional power must be provided. A weight and balance study of the aircraft should be accomplished. Adequate equipment should be provided at a Civil Defense Regional Center to receive and process the data. A flight test program designed to simulate actual missions should then be initiated.

System tests should include ground operational checks as well as a flight test program. The radiation may be simulated by causing remotely operated standard sources (Section 7.5.2) to be driven in and out of the field of detection of the sensors. The data system can be exercised by simulating dose rate levels in the aircraft for various geographic positions on the ground.

The needs of the user at the national and regional level should be examined in terms of possible responses that can be made to various types of radiological reporting. This data will help to define the amount of detail and accuracy desired from the survey which in turn sets the number of aircraft needed for the survey and the dose rate levels to be reported. Stanford Research Institute and Edgerton, Germeshausen and Grier, Inc., are currently engaged in studies relating to this problem.

APPENDIX A

(to Section 7)

Listed below is some representative electronic equipment of the type suitable for use in the detector channels. All of the equipment is of modular construction, and is fully transistorized. Low voltage DC power for operation is required for these units; the operating power may be obtained from a master power supply, or from smaller supplies for each unit.

Amplifier, RCL* Model 20112 4" x 9" x 12"	4 lb	$535
Amplifier, RIDL** Model 30-20 4" x 9" x 10"	3 lb	$425
Logarithmic Ratemeter, RCL Model 20408 4" x 9" x 12"	5 lb	$725
Logarithmic Ratemeter, RIDL Model 35-7 4" x 9" x 10"	3 lb	$475
High Voltage Power Supply, RCL Model 20703 4" x 9" x 12"	5 lb	$615
High Voltage Power Supply, RILD Model 40-9		$495
High Voltage Power Supply, ERA*** Model HAR3K/2		$285

RCL* = Radiation Counter Laboratories, Skokie, Illinois

RIDL** = Radiation Instrument Development Laboratory, Inc., Melrose Park, Illinois

ERA*** = Electronic Research Associates, Inc., Cedar Grove, N.J.

APPENDIX B

List of companies making components usable in the proposed data systems.

Ampex Corporation, Redwood City, California

1. Digital Tape Transport FR200
2. Tape Recorder/Reproducer FR100

Avion Division - ACF Industries, Inc., Paramus, New Jersey

1. Analog to Digital Converter
2. Digital to Analog Converter

Bendix Pacific, Bendix Aviation Corporation, North Hollywood, Calif.

1. FM/FM T/M Transmitter
2. FM RF Amplifier
3. Voltage Controlled Oscillator
4. Subcarrier Discriminator
5. Search Radar APS 88
6. Radar Transponder APN 134

Collins Radio Company, Richardson, Texas

1. Long Range Radio
2. Kineplex Data Transmission System
3. Data Modem TE 204
4. Teletype Adapter 399R-1
5. CV 786 Data Modem
6. Digital Data System

Computer Control Company, Inc., Framingham, Mass.

1. Master Oscillator
2. Synchronous Generator
3. Shift Register

Consolidate Electronics, Subsidiary of Bell and Howell, Pasadena, Calif.

1. Recording Oscillograph

Data-Control System, Inc., Danbury, Conn.

1. Multiplexer
2. Voltage Controlled Oscillator
3. FM RF Amplifier
4. Subcarrier Discriminator
5. Pulse Synchronizer
6. Power Inverter

Data-tronix Corporation, Norristown, Penna.

1. Electronic Commutator

Defense Electronics, Rockville, Maryland

1. FM/FM T/M Transmitter
2. FM/FM T/M Receiver
3. FM/FM T/M Multicoupler
4. FM/FM Preamplifier

Digi-Data Corporation, Hyattsville, Maryland

1. Digital Stepping Recorder (magnetic tape)

Di/an Controls, Inc., Boston, Mass.

1. Magnetic Shift Register

Dynamic System Electronic, Phoenix, Arizona

1. Combination Analog to Digital Converter and Multiplexer
2. Digital to Analog Converter
3. Power Supplies

Elasco Incorporation, Roxbury, Conn.

1. Power Supplies

Electronic Communications, Inc., St. Petersbur 10, Florida

1. Facsimile Transmitter
2. Data Systems

Electro-Mechanical Research, Inc., Sarasota, Florida

1. Subcarrier Discriminator
2. Subcarrier Oscillator

International Data Systems, Inc., Dallas, Texas

1. Data Systems
2. Digital Data System Components

Magnetic Research Company, White Plains, New York

1. Magnetic Shift Register

Minneapolis-Honeywell, Heiland Division, Denver, Colorado

1. Visicorder
2. Magnetic Tape Recorder

Mnemtron Corporation, Pearl River, New York

1. Magnetic Tape Recorder

Monitor Systems, Inc., Sub. of Epsco Inc.

1. Multiplexer
2. Analog to Digital Converter
3. Digital Tape Recorder

F. W. Mosely Company, Pasadena, California

1. Magnetic Tape Control Unit
2. Tape Converter
3. X-Y Recorder

Potter Instrument Company, Inc., Plainview, New York

1. Digital Tape System

Ransom Research, Division of Wyle Labs., San Pedro, California

1. Power Supplies
2. Shift Register

Sanborn Company, Waltham 54, Mass.

1. Analog Tape Recorder

Sperry Gyroscope Company, Great Neck, L.I., New York

1. Radar Transponder
2. Search Radar

Standard Products, Inc., Wichita, Kansas

1. Facsimile Transmitter

Systron-Donner Corporation, Concord, Calif.

1. Programmer

Tele-Dynamics, Div. of American Bosch Arma Corporation, Philadelphia, Penna.

1. Voltage Controlled Oscillator
2. FM/FM T/M Transmitter
3. FM RF Amplifier
4. Subcarrier Discriminator
5. FM RF Receiver

Telemetering Corporation of America, Sepulveda, Calif.

1. Multiplexer
2. Amplifier
3. Subcarrier Oscillator
4. FM/FM T/M Transmitter

Teletype Corporation, Subsidiary of Western Electric Company, Inc., Chicago, Illinois

1. Teletype Tape Reader
2. Tape Perforator
3. Tape Perforator and Transmitter

Western Union Telegraph Company, New York, New York

1. Intrafax Facsimile Transmitter
2. Teleprinter

Westrex Corporation, Division of Litton Industries, New York 19, N.Y

1. Facsimile Transmitter and Receiver

United Electro Dynamics, Inc., Pasadena, California

1. FM/FM Telemetry Components
2. Analog to Digital Converter

APPENDIX C

Validity of the Detector Design

In using a two detector γ-ray survey system for the determination of ground contamination from fallout, the following factors must be considered: (1) the air contamination noise, (2) the angular distribution of air-scattered γ-rays at the detector altitude resulting from the distributed ground fallout, (3) variation of the ground source spectrum with time and the relation to the detector-altitude count rate, (4) calibration, (5) the effective area of the ground contamination source seen by the system as a function of altitude, and (6) the use of detector bias to improve the difference of the two detectors. The following is a summary of the above items with principal reference to items (2) and (3).

Considering the case of a surface burst, the air contamination forms a source of radiation assumed uniformly distributed about the aircraft system. The use of a signal + background minus background difference technique for eliminating the air contamination component has been proposed (see 7.4.3); however, the use of such a system pre-supposes the signal (γ-rays coming from the ground fallout) is observed only by the one downward looking detector.

For the 1800-ft altitude considered, the unscattered flux component of γ-rays reaching the detector was calculated to be at least an order of magnitude lower than the air-scattered component. Thus, the main source of signal at the detector is air-scattered γ-rays (assuming low air contamination). The angular distribution of this air-scattered component must be investigated in order to assure that the detector-difference method can be used, e.g., if the γ-ray angular flux at the detector altitude were nearly isotropic, the difference method could not be used.

The angular distribution of air-scattered γ-rays can be approximated by the use of Monte Carlo point isotropic, mono-energetic, infinite-air-medium data (see Ref. 1) assuming a uniform distribution of such sources on the ground. These data were used to evaluate the γ-ray angular flux $N_s(h,\theta)$ as a function of altitude h and angle θ off the vertical axis (Fig. 1) by the equation

$$N_s(h,\theta) = \int_0^{\infty} r dr \int_0^{2\pi} d\phi M(p,\theta)$$

where $M(p,\theta)$ is the Monte Carlo angular distribution corresponding to a separation distance $p = p(h,r)$ resulting from a point isotropic, mono-energetic source of 1 photon/cm^2-sec. (Figure C.1.)

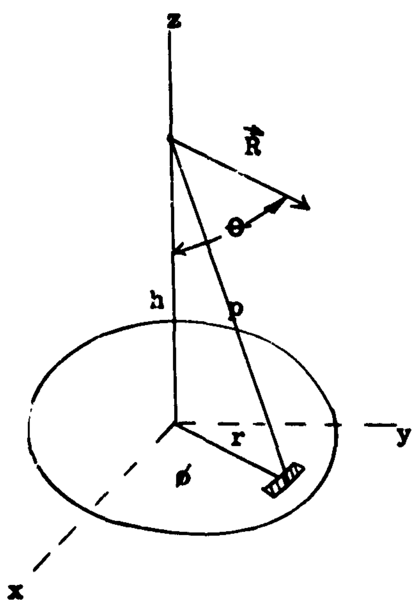


Fig. C.1 Geometry For Distributed Source

The upper limit on the radial integral was replaced by $r = 2h$ for the altitude studied, $h = 1800$ feet. That this is a valid approximation is shown in Figure C.2 where the integrand of the above equation $rM(p,\Theta)$ is plotted against r.

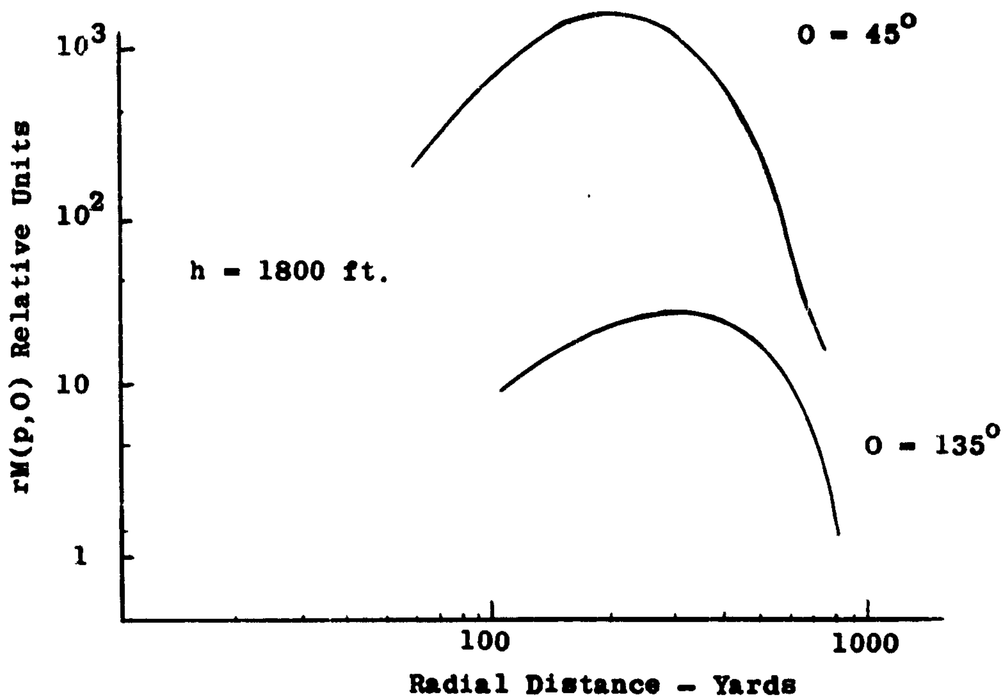


Fig. C.2 Angular Distribution vs. Radial Distance

It can be seen that the contribution to the integral drops rapidly from air attenuation before r = 2h. An additional desirable feature is apparent; the spatial resolution on the ground of the detector system is good enough to detect any average flux changes for which it is designed.

These Monte Carlo calculations were evaluated at 1.0 Mev and at 0.5 Mev. The angular distribution resulting from 1 Mev primary γ-rays, shown in Figure 7.3, is typical of both energies. From Figure C.3 (derived from data in Ref. 2), which shows the gamma spectrum at the ground about 12 hours after a burst, one can see that the major portion of the spectrum falls within the 0.5–1.0 Mev region discussed above. The spectrum is nearly constant during the initial search period, 10–20 hours after detonation.

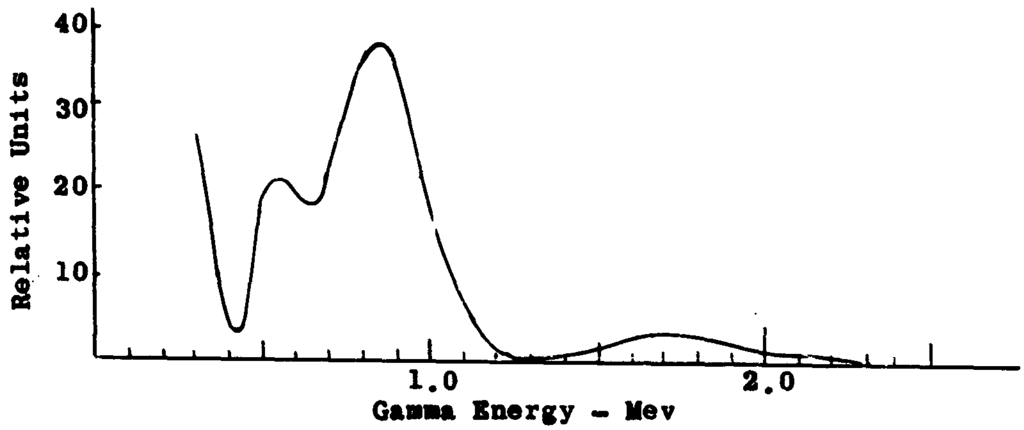


Fig. C.3 Gamma Spectrum at the Ground at (H+12) Hours

Gamma rays of energies less than 0.5 Mev experience only a few scatters before entering the large Compton cross-section region and are absorbed before reaching a height of 1800 feet. The small peak, centered about 1.7 Mev, contributes about as many photons at 1800 feet as does the much larger peak centered about 0.8 Mev because of the greater mean free path at that energy; but the angular distribution of these photons is even more peaked in the vertical direction than are 1 Mev photons. Consequently, the angular distribution of Figure 7.3 is a valid input for the detector design.

The detector design assumes a flat response for all gamma rays impinging upon it so that the count rate for each detector would be directly related to the flux. For the predominantly low-energy, scattered radiation at 1800 feet, this is a valid assumption. Figure C.4 shows the detection efficiency of NaI crystals of differing thicknesses as a function of γ-ray energy.

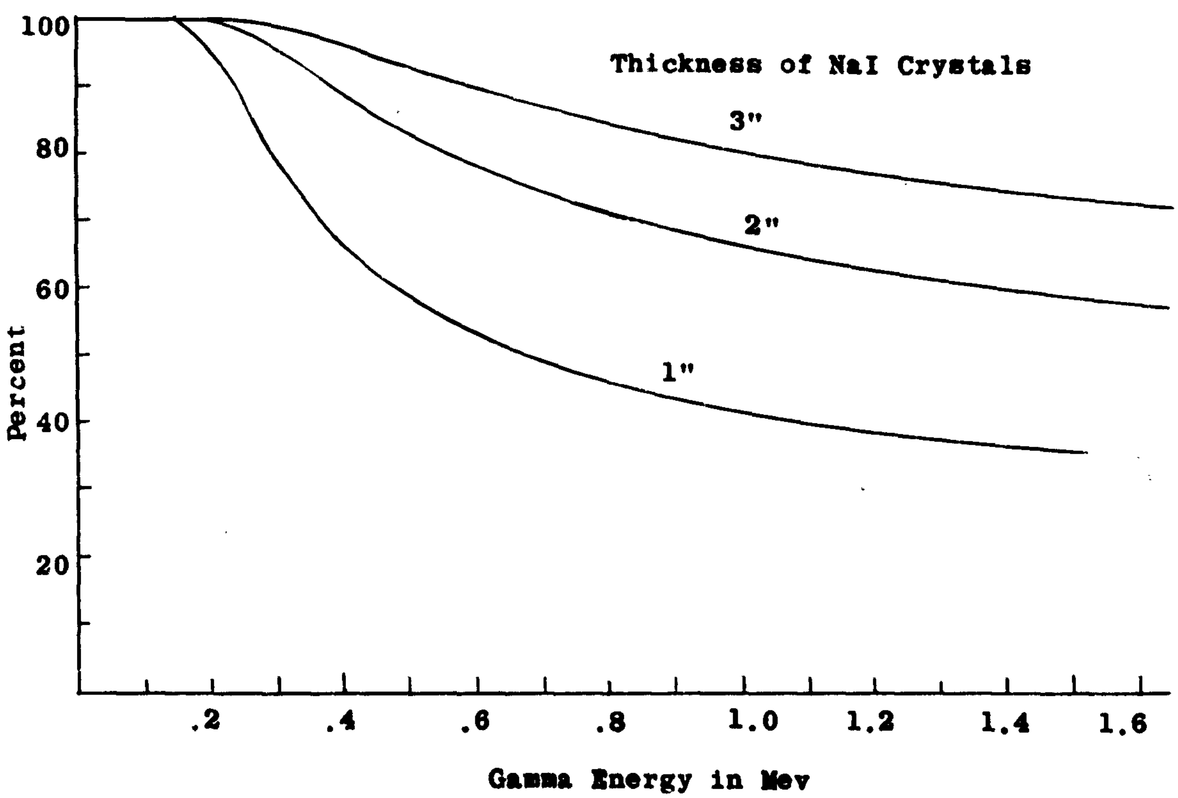


Fig. C.4 Detection Efficiency as a Function of Energy

It can be seen that the efficiency is never less than 66% for all energies below 1 Mev for a 2 inch crystal and is better for a 3 inch crystal. The number of γ-rays of energy greater than this, relative to the total flux, can be expected to be small.

In conclusion, the detector, as designed, appears to satisfy all the conditions it should. If experiment, however, reveals that some of the above calculations were inaccurate by discovering a larger flux than anticipated from the skyward direction, the situation can be corrected by adding a suitable bias level to both detectors. The skyward radiation, having been scattered more often to reverse its direction, is of much less energy than the radiation entering the lower detector and would be preferentially discriminated against. Of course, a bias will reduce the total number of counts to be expected, but these can be increased again by flying at a slightly lower altitude.

Calibration of the detector depends upon overcoming two difficulties. First, the spectrum at the ground is changing as a function of time and extends over a broad band of energies, from nearly 0 to 2.8 Mev. Second, the distribution from any energy interval of the spectrum to the flux at any altitude is a function of the altitude. For example, from Figure C.3 one can see that at the ground level the peak at 0.8 Mev is approximately 10 times as large as the peak at 1.7 Mev. Yet, at 2200 feet, the contribution to the flux from these two peaks is about equal. At a still higher altitude, the contribution from the 0.8 Mev peak would disappear and only the flux arising from the 1.7 Mev peak would still be present. The same flux would be present if a single energy source of 1.7 Mev and the proper intensity were present on the ground. However, a calibration based on this source would be misleading since it would tell nothing about the dose at the ground from the rest of the spectrum. At lower altitudes where other portions of the spectrum contribute to the flux, the relative contributions are changing and the simulation of the flux at a range of altitudes by use of discrete energy radioisotopes becomes almost impossible.

Both difficulties can be overcome by calibrating the detector at various altitudes above this source, using a fresh fuel element, irradiated for a few hours, as a source. The fuel element will closely approximate the energy of the fallout radiation as a function of time. Having a fuel element as a source eliminates any uncertainty as to how well the flux at altitude represents the true spectrum at the ground. It is only necessary to calibrate the detector at several altitudes above the source so that the constants of the equation below can be determined. The use of this equation is discussed in Section 8.6.9.

$$\phi(h) = \phi_o S ae^{-bh}$$

$\phi(h)$ is the measured flux at altitude.

ϕ_o is $\dfrac{\gamma\text{'s/cm}^2\text{/sec}}{\text{R/hr}}$ for the source spectrum, measured at the ground, and thereafter treated as a constant.

S is the source strength of R/hr, measured at the ground.

h is the altitude,

b,a, are constants to be determined.

In actual survey work, S is the unknown and the equation to be solved becomes

$$S = \frac{\phi(h)}{\phi_o a} e^{+bh}$$

References

Ref. 1 M. B. Wells, "A Monte Carlo Calculation of Gamma-Ray and Fast Neutron Scattering," Proceedings of NRDL-OCDM Shielding Symposium, 31 October, 1 November 1960. (U)

Ref. 2 E. T. Clarke and J. O. Buchanan, "Radiation Shielding Against Fallout," Technical Operations Research, Inc. Nucleonics Vol. 20, No. 8, August 1962, pp 143-146.

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