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Fire Controlman, Volume 2—Fire-Control Systems and Radar Fundamentals

NAVEDTRA 14099A

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PREFACE

About this course:

This is a self-study course. By studying this course, you can improve your professional/military knowledge, as well as prepare for the Navywide advancement-in-rate examination. It contains subject matter about day-to-day occupational knowledge and skill requirements and includes text, tables, and illustrations to help you understand the information. An additional important feature of this course is its references to useful information in other publications. The well-prepared Sailor will take the time to look up the additional information.

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Course assignments follow the index.

CHAPTER 1

INTRODUCTION TO BASIC RADAR SYSTEMS

LEARNING OBJECTIVES

Upon completing this chapter, you should be able to do the following:

1. Explain the terms “range,” “bearing,” and “altitude” as they are associated with radar.
2. Explain the two basic methods for detecting objects with radar.
3. Identify and explain the use of equipment found in basic radar.
4. Identify and state the use of the four basic types of military radar systems.
5. Identify and explain the three phases of fire-control radar.
6. Identify the radar systems currently used in the U. S. Navy.

INTRODUCTION

This chapter discusses radar principles and basic radar systems. As a Fire Controlman, and a possible work-center supervisor, you must understand basic radar principles and safety requirements for radar maintenance. You will find valuable supporting information in the Navy Electricity and Electronics Training Series (NEETS), especially Module 18, *Radar Principles*, NAVEDTRA 14190, and in *Electronics Installation and Maintenance Book, Radar*, NAVSEA SE000-00-EIM-020. By referring to these publications on a regular basis, you can increase your understanding of this subject matter.

This chapter is not designed to teach you every radar system the Navy uses, but simply to familiarize you with the radars and their general characteristics. Because there are so many different models of radar equipment, we will describe only the radars and radar accessories that will be around for several years. We will not discuss older radar systems that are scheduled for replacement in the near future. Refer to your specific technical publications for detailed descriptions of the operation and maintenance of your specific radar system.

BASIC RADAR CONCEPTS

The term *radar* is an acronym made from the words ***ra****dio*, ***d****etection*, ***a****nd* ***r****anging*. It refers to electronic equipment that uses reflected electromagnetic energy to determine the direction to, height of, and distance of detected objects. Electromagnetic energy of the frequency used for radar is unaffected by darkness. However, it can be affected by weather to some degree, depending on its frequency. It permits radar systems to determine the positions of ships, planes, and land masses that are invisible to the naked eye because of distance, darkness, or weather. Radar systems provide only a limited field of view and require reference coordinate systems to define the positions of detected objects. Radar surface angular measurements are normally made in a clockwise direction from true north, as shown in figure 1-1, or from the heading line of the ship or aircraft. The radar is located at the center of this coordinate system.

Table 1-1 defines the basic terms used in figure 1-1. You must know these terms to understand the coordinate system.

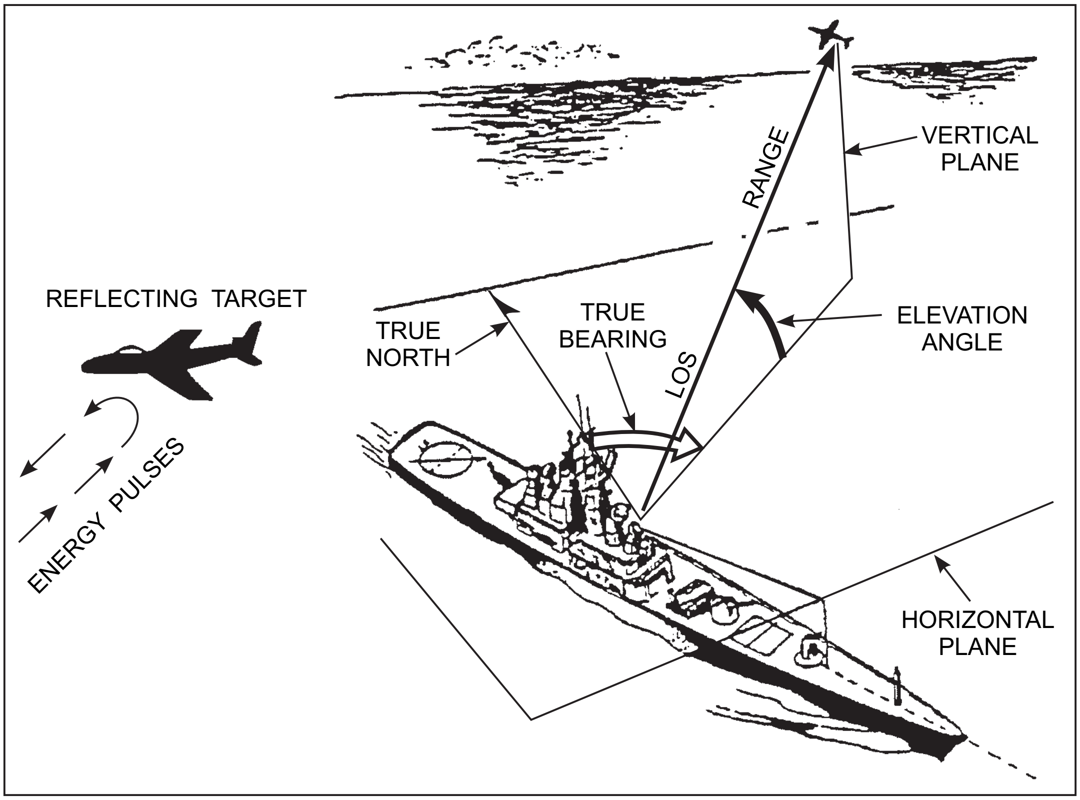

Figure 1-1.—Radar surface angular measurements.

Table 1-1.—Radar Reference Coordinate Terms

Term	Definition
Energy pulses	The pulses that are sent out by the radar and are received back from the target.
Reflecting target	The air or surface contact that provides an echo.
True north	The direction of the north geographical pole.
True bearing/azimuth	The angle measured clockwise from true north in the horizontal plane.
Line-of-sight range	The length of the line from the radar set directly to the object.
Vertical plane	All angles in the up direction, measured in a secondary imaginary plane.
Elevation angle	The angle between the horizontal plane and the line of sight.
Horizontal plane	The surface of the Earth, represented by an imaginary flat plane which is tangent (or parallel) to the Earth's surface at that location.

RADAR MEASUREMENTS

We stated earlier that radar is used to determine the distance and direction to and the height of distant objects. These three pieces of information are known, respectively, by the standard terms range, bearing, and altitude. The use of these standard terms allows anyone interested in a specific target to establish its position quickly and accurately. Radar operators determine a target's range, bearing, and altitude by interpreting its position displayed on a specially designed cathode-ray tube (CRT) installed in a unit known as a plan position indicator (PPI).

While most radars are used to detect targets, some types are used to guide missiles to targets and to direct the firing of gun systems; other types provide long-distance surveillance and navigation information.

Range and bearing (and in the case of aircraft, altitude) are necessary to determine target movement. To be a successful radar operator, you must understand the capabilities and limitations of your radar system in determining range, bearing, and altitude.

Range

The radar measurement of range (or distance) is possible due to the properties of radiated electromagnetic energy. This energy normally travels through space in a straight line, at a constant speed, and varies only slightly due to atmospheric and weather conditions. The frequency of the radiated energy causes the radar system to have both a minimum effective range and a maximum effective range.

MINIMUM RANGE.—Radar duplexers alternately switch the antenna between the transmitter and the receiver so that one antenna can be used for both functions. The timing of this switching is critical to the operation of the radar and directly affects the minimum range of the radar system. A reflected pulse will not be received during the transmit pulse and subsequent receiver recovery time. The minimum range of a radar, therefore, is the minimum distance between the radar's antenna and a target at which a radar pulse can be transmitted, reflected from the target, and received by the radar receiver. If the antenna is closer to the target than the radar's minimum range, any pulse reflected from the target will return before the receiver is connected to the antenna and will not be detected.

MAXIMUM RANGE.—The maximum range of a pulse-radar system depends on carrier frequency; peak power of the transmitted pulse; pulse-repetition frequency (PRF) or pulse-repetition rate (PRR) (PRF and PRR are synonymous terms); and receiver sensitivity, with PRF/PRR as the primary limiting factor.

The peak power of a pulse determines how far the pulse can travel to a target and still return a usable echo. A usable echo is the weakest signal that a receiver can detect, process, and present on a display.

The PRR determines the rate at which the range indicator is reset to zero. As the leading edge of each pulse is transmitted, the indicator time base used to measure the returned echo is reset, and a new sweep appears on the screen.

RANGE ACCURACY.—The shape and width of the radio-frequency (RF) pulse influences minimum range, range accuracy, and maximum range. The ideal pulse shape is a square wave that has vertical leading and trailing edges. The vertical edge provides a definite point from which to measure elapsed time on the indicator time base. A sloping trailing edge lengthens the pulsewidth. A sloping leading edge provides no definite point from which to measure elapsed time on the indicator time base.

Other factors affecting range are the antenna's height, beamwidth, and rotation rate. A higher antenna will create a longer radar horizon, allowing a greater range of detection. An antenna with a narrow beamwidth, provides a greater range capability, since it provides more concentrated beam with a higher energy density per unit area. A slower antenna rotation rate, providing more transmitted pulses during the sweep, allows the energy beam to strike each target more times, providing stronger echo returns and a greater detection range.

From the range information, the operator knows the distance to an object. He now needs bearing information to determine where the target is in reference to the ship.

Bearing

Radar bearing is determined by the echo's signal strength as the radiated energy lobe moves past the target. Since search radar antennas move continuously, the point of maximum echo return is determined either by the detection circuitry as the beam passes the target or visually by the operator. Weapons control and guidance radar antennas are positioned to the point of maximum signal return and are maintained at that position either manually or by automatic tracking circuits.

You need to be familiar with two types of bearing: true and relative.

TRUE BEARING.—True bearing is the angle between true north and a line pointed directly at the target. This angle is measured in the horizontal plane and in a clockwise direction from true north.

RELATIVE BEARING.—Relative bearing is the angle between the centerline of the ship and a line pointed directly at the target. This angle is measured in a clockwise direction from the bow. Most surface-search radars provide only range and bearing information. Both true and relative bearing angles are illustrated in figure 1-2.

Altitude

Altitude or height-finding radars use a very narrow beam in the vertical plane. This beam is scanned in elevation, either mechanically or electronically, to pinpoint targets. Tracking and weapons-control radar systems in current use scan the beam by moving the antenna mechanically or the radiation source electronically.

Most air-search radars use electronic elevation scanning techniques. Some older air-search radar systems use a mechanical elevation scanning device; but these are being replaced by electronic scanning radar systems.

RADAR TRANSMISSION METHODS

Radar systems are normally divided into two operational categories (purposes) based on their method of transmitting energy. The most common method, used for applications from navigation to fire control, is the *pulse-modulation* method. The other method of transmitting is *continuous-wave* (CW). CW radars are used almost exclusively for missile guidance.

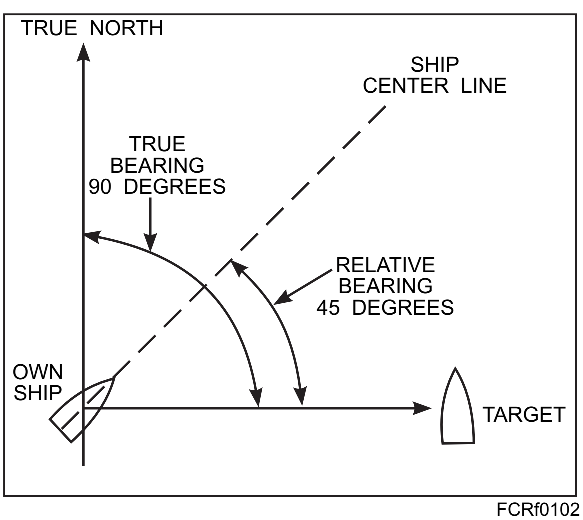

Figure 1-2.—True and relative bearings.

Pulse Modulation

In the pulse method, the radar transmits the RF in a short, powerful pulse and then stops and waits for the return echo. By measuring the elapsed time between the end of the transmitted pulse and the received echo, the radar can calculate a range. Pulse radars use one antenna for both transmitting and receiving. While the transmitter is sending out its high-power RF pulse, the antenna is connected to the transmitter through a special switch called a *duplexer*. As soon as the transmitted pulse stops, the duplexer switches the antenna to the receiver. The time interval between transmission and reception is computed and converted into a visual indication of range in miles or yards. Pulse-radar systems can also be modified to use the Doppler effect to detect a moving object. The Navy uses pulse radars to a great extent.

Continuous Wave

In a CW radar the transmitter sends out a "continuous wave" of RF energy. Since this beam of RF energy is "always on," the receiver requires a separate antenna. One disadvantage of this method is that an accurate range measurement is impossible because there is no specific "stop time." This can be overcome, however, by modulating the frequency. A frequency-modulated continuous wave (FM-CW) radar can detect range by measuring the difference between the transmitted frequency and the received frequency. This is known as the "Doppler effect." The continuous-wave method is usually used by fire-control systems to illuminate targets for missile systems.

RADAR SYSTEM ACCURACY

To be effective, a radar system must provide accurate indications. That is, it must be able to determine and present the correct range, bearing, and, in some cases, altitude of an object. The degree of accuracy is primarily determined by two factors: the resolution of the radar system and existing atmospheric conditions.

Range Resolution

Range resolution is the ability of a radar to distinguish between two targets on the same bearing, but at slightly different ranges. The degree of range resolution depends on the width of the transmitted pulse, the types and sizes of the targets, and the efficiency of the receiver and the indicator.

Bearing Resolution

Bearing, or azimuth, resolution is the ability of a radar system to separate objects at the same range, but at slightly different bearings. The degree of bearing resolution depends on the radar's beamwidth and the range of the targets. The physical size and shape of the antenna determines beamwidth. Two targets at the same range must be separated by at least one beamwidth to be distinguished as two objects.

Atmospheric Conditions

Several conditions within the atmosphere can have an adverse effect on radar performance. A few of these are temperature inversion, moisture lapse, water droplets, and dust particles.

The temperature and moisture content of the atmosphere normally decrease uniformly with an increase in altitude. However, under certain conditions the temperature may first increase with height and then begin to decrease. Such a situation is called a *temperature inversion.* An even more important deviation from normal may exist over the ocean. Since the atmosphere close to the surface over large bodies of water may contain more than a normal amount of moisture, the moisture content may decrease more rapidly at heights just above the sea. This effect is referred to as *moisture lapse*.

Either temperature inversion or moisture lapse, alone or in combination, can cause a large change in the refraction index of the lowest few-hundred feet of the atmosphere. The result is a greater bending of the radar waves passing through the abnormal condition. This increase in bending, referred to as *ducting*, may greatly affect radar performance. The radar horizon may be extended or reduced, depending on the direction in which the radar waves are bent. The effect of ducting is illustrated in figure 1-3.

Water droplets and dust particles diffuse radar energy through absorption, reflection, and scattering. This leaves less energy to strike the target, so the return echo is smaller. The overall effect is a reduction in usable range. Usable range varies widely with such weather conditions. The higher the frequency of the radar system, the more it is affected by weather conditions, such as rain or clouds.

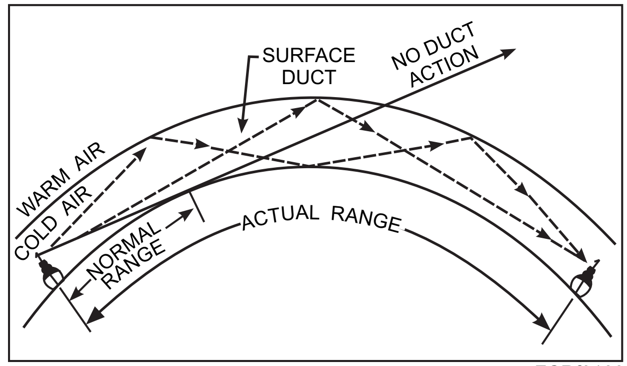

Figure 1-3.—Ducting effect on the radar wave.

Other Factors

Some other factors that affect radar performance are operator skill; size, composition, angle, and altitude of the target; possible Electronic Attack (EA) activity; readiness of equipment (completed planned maintenance system requirements); and weather conditions.

BASIC RADAR SYSTEMS

Radar systems, like other complex electronics systems, are composed of several major subsystems and many individual circuits. Although modern radar systems are quite complicated, you can easily understand their operation by using a basic block diagram of a pulse-radar system.

FUNDAMENTAL (PULSE) RADAR SYSTEM

Since most radars used today are some variation of the pulse-radar system, this section discusses components used in a pulse radar. All other types of radars use some variation of these units. Refer to the block diagram in figure 1-4.

Synchronizer

The heart of the radar system is the *synchronizer.* It generates all the necessary timing pulses (triggers) that start the transmitter, indicator sweep circuits, and ranging circuits. The synchronizer may be classified as either self-synchronized or externally synchronized. In a self-synchronized system, pulses are generated within the transmitter. Externally synchronized system pulses are generated by some

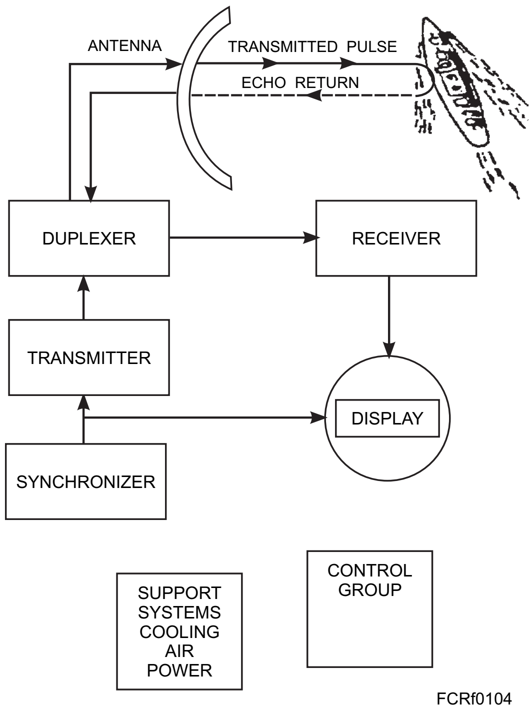

Figure 1-4.—Basic radar block diagram.

type of master oscillator external to the transmitter, such as a modulator or a thyratron.

Transmitter

The transmitter generates powerful pulses of electromagnetic energy at precise intervals. It creates the power required for each pulse by using a high-power microwave oscillator (such as a magnetron) or a microwave amplifier (such as a klystron) supplied by a low power RF source.

For further information on the construction and operation of microwave components, review NEETS Module 11, *Microwave Principles*, NAVEDTRA 14183.

Duplexer

The duplexer is basically an electronic switch that permits a radar system to use a single antenna to transmit and receive. The duplexer disconnects the antenna from the receiver and connects it to the transmitter for the duration of the transmitted pulse. The switching time is called *receiver recovery time*, and must be very fast if close-in targets are to be detected.

Receiver

The receiver accepts the weak RF echoes from the antenna system and routes amplified pulses to the display as discernible video signals. Because the radar frequencies are very high and difficult to amplify, a superheterodyne receiver is used to convert the echoes to a lower frequency, called the *intermediate frequency* (IF), which is easier to amplify.

Displays

Most of the radars that FCs operate and maintain have a display, or multiple displays, to provide the operator with information about the area the radar is searching or the target, or targets, being tracked. The usual display is a cathode-ray tube (CRT) that provides a combination of range, bearing (azimuth), and (in some cases) elevation data. Some displays provide raw data in the form of the signal from the radar receiver, while others provide processed information in the form of symbology and alphanumerics.

Figure 1-5 shows four basic types of displays. There are other variations, but these are the major types encountered in fire control and 3-D search radars.

TYPE A.—The type A sweep, or range sweep, display shows targets as pulses, with the distance from the left side of the trace representing range. Variations in target amplitude cause corresponding changes in the displayed pulse amplitude. The display may be bipolar video when used with Moving Target Indicator (MTI) or pulse Doppler radars.

TYPE B.—The type B sweep, or bearing sweep, is mostly found with gunfire control radars and is used with surface gunfire to spot the fall of shot. The range may be full range or an interval either side of the range gate.

TYPE E.—Two variations of type E are shown. Both provide range and elevation (or height) of a target. These are associated with height-finding radars and are generally used to determine the height or elevation angle only. Range is determined from processing or a type P display.

TYPE P.—This display is commonly called a PPI (plan position indicator). Own ship is usually the center. Range is measured radially from the center. The range display can be selected, and the radar source is usually selectable. The PPI can display raw video or symbology and alphanumerics, or both. The type P display is most commonly found in the Combat Information Center (CIC) and in weapons control stations.

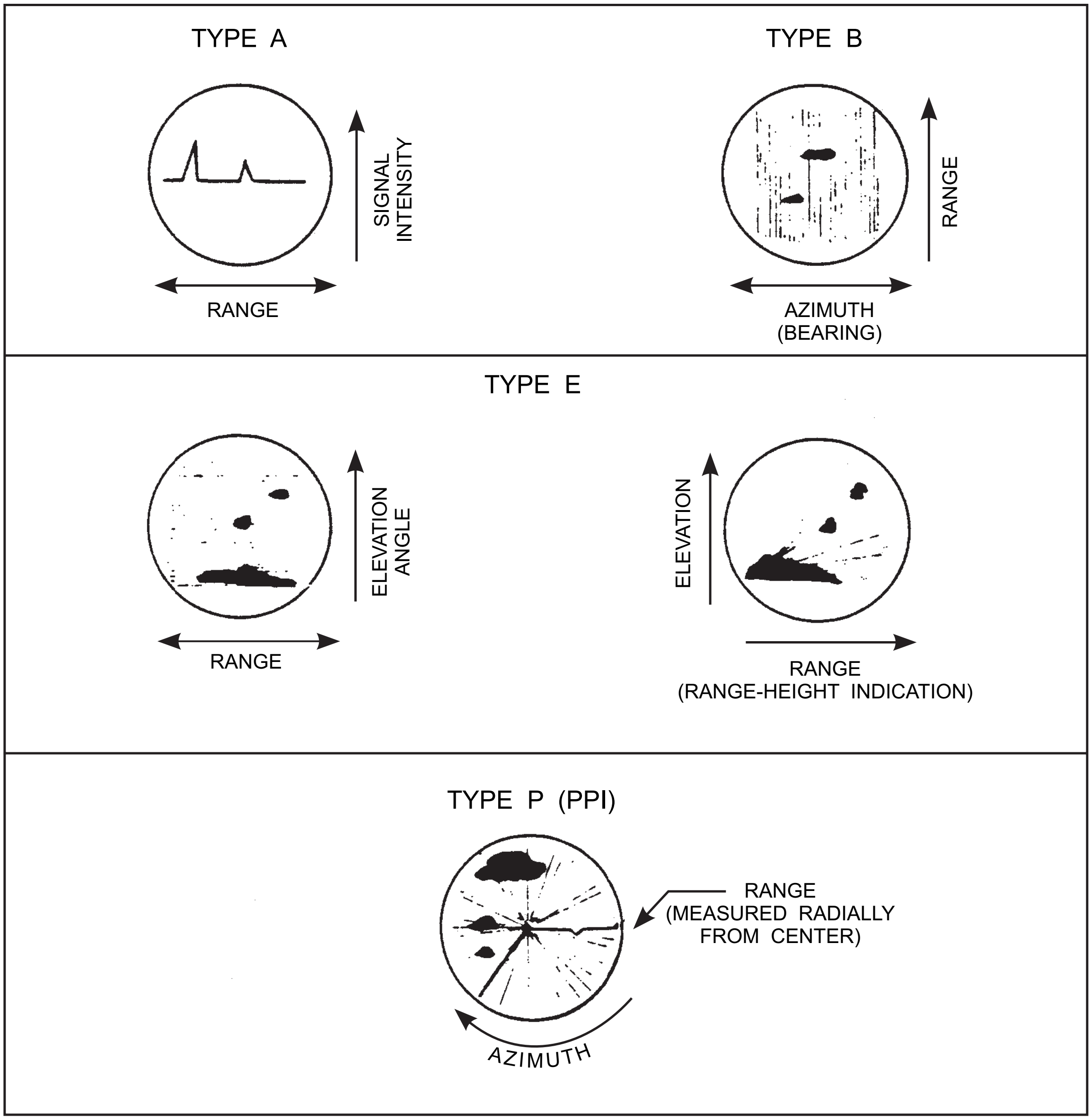

Figure 1-5.—Types of radar displays.

Additional information on how individual displays are produced is available in NEETS modules 6, 9, and 18.

Antenna System

The antenna system routes the pulse from the transmitter, radiates it in a directional beam, picks up the returning echo, and passes it to the receiver with a minimum of loss. The antenna system includes the antenna; transmission lines and waveguide from the transmitter to the antenna; and transmission lines and waveguide from the antenna to the receiver.

Before we discuss some types of antennas used in fire control, we need to review the basic principles of electromagnetic wave radiation and reflectors.

The radar energy that forms the target-tracking and illumination beams is transmitted by an antenna at the control point. Radiated energy tends to spread out equally in all directions, as shown in figure 1-6. Figure 1-6 compares the radiation from a radio antenna with that from a lamp. Both light waves and radio waves are electromagnetic radiation; the two are believed to be identical, except in frequency of vibration. From both sources, energy spreads out in spherical waves. Unless they meet some obstruction, these waves will travel outward indefinitely at the speed of light.

The energy at any given point decreases with range since the wave, and therefore the energy, is spreading out to cover a larger area. Because of its much higher frequency, light has a much shorter wavelength than a radio wave. This is suggested in figure 1-6 but it cannot be shown accurately to scale. The wavelength of a radar transmission may be measured in centimeters, whereas the wavelength of light varies from about three to seven ten-thousandths of a millimeter. We mentioned earlier that radio wave energy must be concentrated to be useful. We can concentrate this energy by mounting a suitable reflector behind the antenna, to form a large part of the radiated energy into a relatively narrow beam. The following paragraphs discuss the more commonly used reflectors.

PARABOLIC REFLECTORS.—You should be familiar with the use of polished reflectors to form beams of light. An automobile headlight uses a parabolic reflector to produce a fairly wide beam. A spotlight uses a slightly differently shaped parabolic reflector to produce a more narrow beam.

A type of reflector generally used in missile fire-control radars is the *parabolic dish*. It is similar in appearance to the reflector used in an automobile headlight. Since radar operates in the microwave region of the electromagnetic spectrum, its waves have properties and characteristics similar to those of light. This permits radar antennas to be designed using well-known optical design techniques.

A basic principle of optics is that a light ray striking a reflecting surface at a given angle will reflect from that surface at the same angle. Now refer to figure 1-7. Think of the circular wavefronts generated by source F as consisting of an infinite number of rays. The antenna's parabolic reflecting surface is designed, using the reflection principle, so that as the circular wavefronts strike the reflector, they are reflected as straight wavefronts. This action concentrates them into a narrow circular beam of energy.

HORN RADIATORS.—Horn radiators (fig. 1-8), like parabolic reflectors, may be used to create concentrated electromagnetic waves. Horn radiators are readily adaptable for use with waveguides because they serve both as an impedance-matching device and as a directional radiator. Horn radiators may be fed by coaxial or other types of lines.

Horns are constructed in a variety of shapes, as illustrated in figure 1-8. The shape of the horn, along with the dimensions of the length and mouth, largely determines the beam's shape. The ratio of the horn's

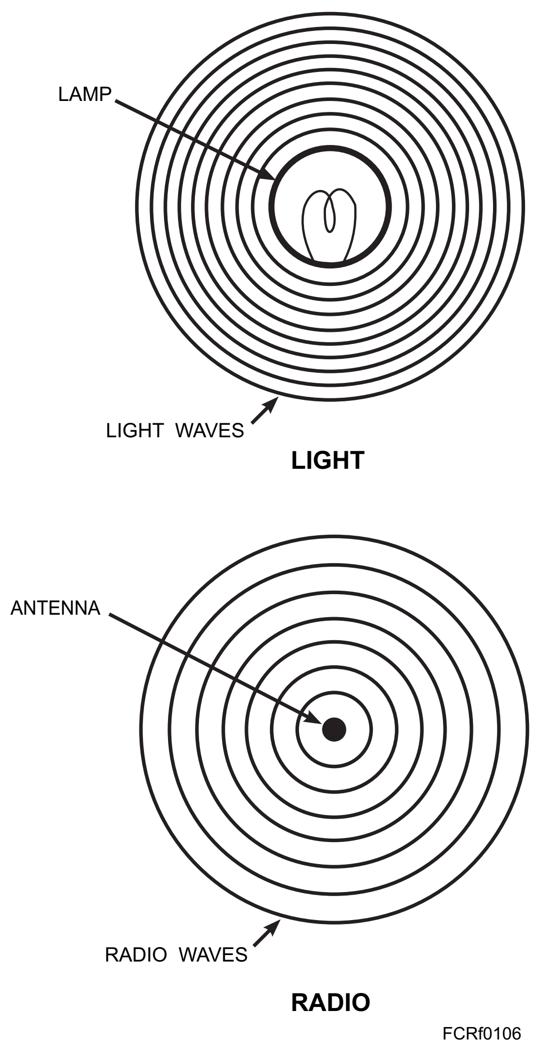

Figure 1-6.—Radiation waves from a radio antenna and a lamp.

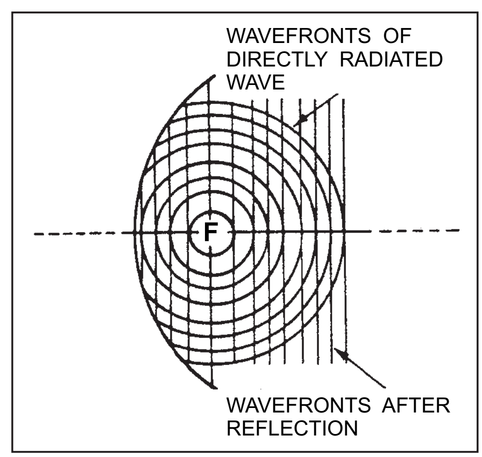

Figure 1-7.—Principles of the parabolic reflector.

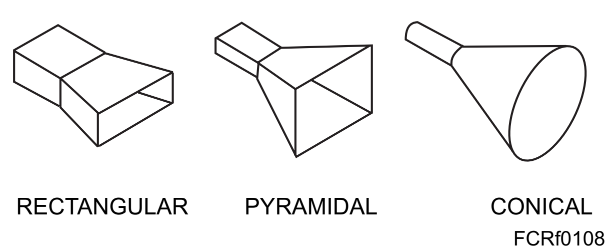

Figure 1-8.—Horn radiators.

length to mouth opening size determines the beamwidth and thus the directivity. In general, the larger the opening of the horn, the more directive is the resulting field pattern.

FEEDHORNS.—A waveguide horn may be used to feed into a parabolic dish. The directivity of this horn, or feedhorn, is then added to that of the parabolic dish. The resulting pattern (fig. 1-9, view A) is a very narrow and concentrated beam. Such an arrangement is ideally suited for fire control use. In most radars, the feedhorn is covered with a window of polystyrene fiberglass to prevent moisture and dirt from entering the open end of the waveguide.

One problem associated with feedhorns is the shadow introduced by the feedhorn if it is in the path of the beam. (The shadow is a dead spot directly in front of the feedhorn.) To solve this problem the feedhorn can be offset from center (fig. 1-9, view B). This takes it out of the path of the RF beam, thus eliminating the shadow.

LENS ANTENNA.—Another antenna that can change spherical waves into flat plane waves is the lens antenna. This antenna uses a microwave lens, which is similar to an optical lens to straighten the spherical wavefronts. Since this type of antenna uses a lens to straighten the wavefronts, its design is based on the laws of refraction, rather than reflection.

Two types of lenses have been developed to provide a plane-wavefront narrow beam for tracking radars, while avoiding the problems associated with the feedhorn shadow. These are the *conducting* (acceleration) type and the *dielectric* (delay) type.

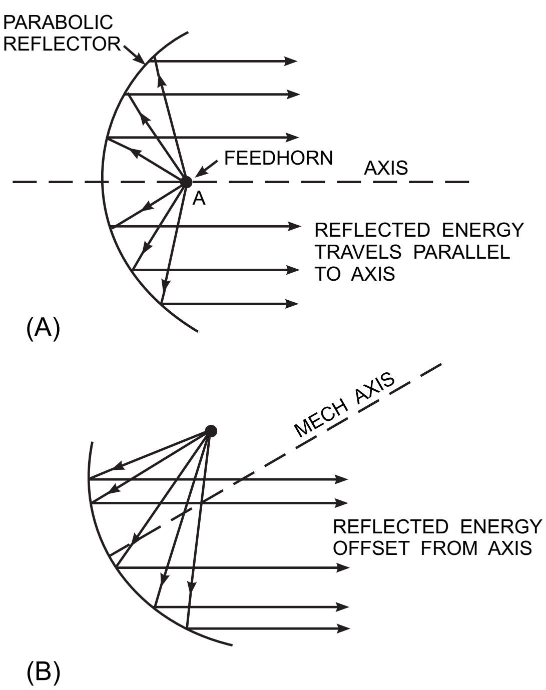

Figure 1-9.—Reflector with feedhorn.

The lens of an antenna is substantially transparent to microwave energy that passes through it. It will, however, cause the waves of energy to be either converged or diverged as they exit the lens. Consider the action of the two types of lenses.

The conducting type of lens is illustrated in figure 1-10, view A. This type of lens consists of flat metal strips placed parallel to the electric field of the wave and spaced slightly in excess of one-half of a wavelength. To the wave these strips look like parallel waveguides. The velocity of phase propagation of a wave is greater in a waveguide than in air. Thus, since the lens is concave, the outer portions of the transmitted spherical waves are accelerated for a longer interval of time than the inner portion. The spherical waves emerge at the exit side of the conducting lens (lens aperture) as flat-fronted parallel waves. This type of lens is frequency sensitive.

The dielectric type of lens, shown in figure 1-10, view B, slows down the phase propagation as the wave passes through it. This lens is convex and consists of dielectric material. Focusing action results from the difference between the velocity of propagation inside the dielectric and the velocity of propagation in the air. The result is an apparent bending, or refracting, of the waves. The amount of delay is determined by the dielectric constant of the material. In most cases, artificial dielectrics, consisting of conducting rods or spheres that are small compared to the wavelength, are used. In this case, the inner portions of the transmitted

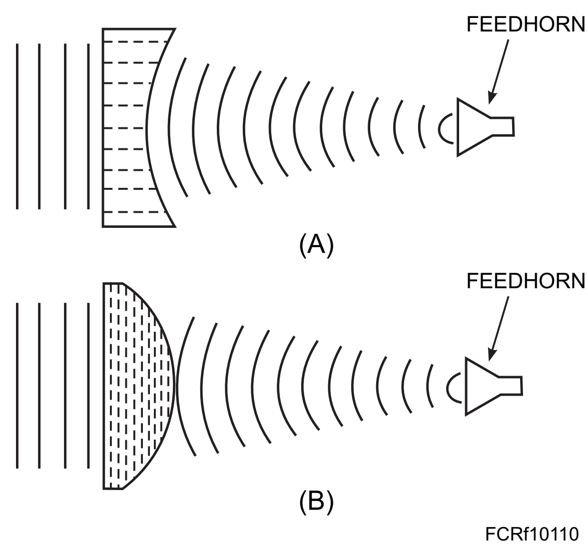

Figure 1-10.—Antenna lenses: A. Conducting (acceleration) type of microwave lens; B. Dielectric (delay) type of microwave lens.

waves are decelerated for a longer interval of time than the outer portions.

In a lens antenna, the exit side of the lens can be regarded as an aperture across which there is a field distribution. This field acts as a source of radiation, just as do fields across the mouth of a reflector or horn. For a returning echo, the same process takes place in the lens.

ARRAY ANTENNAS.—An array type of antenna is just what the name implies—an array or regular grouping of individual radiating elements. These elements may be dipoles, waveguide slots, or horns. The most common form of array is the planar array, which consists of elements linearly aligned in two dimensions—horizontal and vertical—to form a plane (fig. 1-11).

Unlike the lens or parabolic reflector, the array applies the proper phase relationship to make the wavefront flat before it is radiated by the source feed. The relative phase between elements determines the position of the beam; hence the often used term, *phased array.* This phase relationship is what allows the beam to be rotated or steered without moving the antenna. This characteristic of array antennas makes it ideal for electronic scanning or tracking. (We will discuss scanning shortly.)

Radomes

The term *radome* is a combination of the words *radar* and *dome*. Radomes are used to cover and protect radar antennas from environmental effects such as wind, rain, hail, snow, ice, sand, salt spray, lightening, heat, and erosion. The ideal radome is

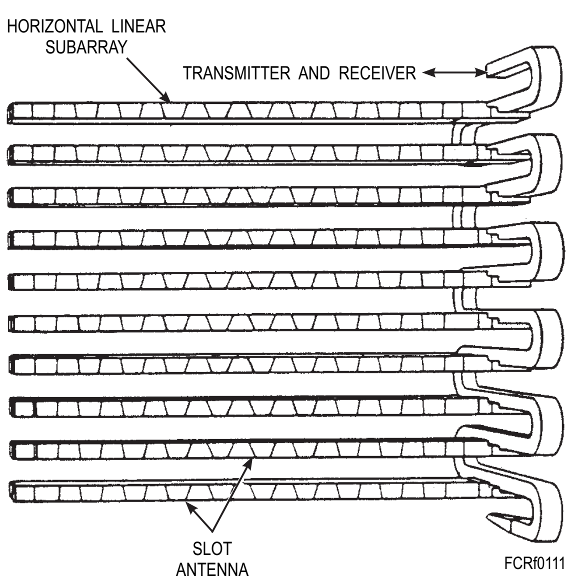

Figure 1-11.—Planar array antenna.

transparent to the RF radiation from the antenna and its return pulses and protects the antenna from the environment. A radome's design is based on the expected environmental factors and the mechanical and electronic requirements of the RF antenna.

Although, in theory, a radome may be invisible to RF energy, in real life the radome effects the antenna's performance in four ways. These are; *beam deflection*, *transmission loss*, *reflected power*, and *secondary effects*. *Beam deflection* is the shift of the RF beam's axis. This is a major consideration with tracking (i.e., FC) radar. *Transmission loss* is the loss of energy associated with reflection and absorption within the radome. *Reflected power* can cause antenna mismatch in small radomes and sidelobes in large radomes. Depolarization and increased antenna noise are a result of *secondary effects*.

As an FC, you will be primarily responsible for maintaining the radome associated with your equipment. This normally will include routine cleaning and inspection according to your prescribed preventive maintenance schedule. Some minor repairs may be authorized by your technical manuals, but most repairs will normally be done by an authorized factory representative. You may be required to repaint the radome because of normal environmental wear and tear. If so, be especially careful to use only paint(s) authorized by the manufacturer and to follow the authorized step-by-step procedures.

Figure 1-12 is an example of a radome in use in today's Navy. Other systems that use radomes include, the Combined Antenna System of the Mk 92 Fire Control System, the AN/SPQ-9 series antenna for the Mk 86 Gun Fire Control System, and the Mk 23 Target Acquisitioning System for the SEASPARROW missile system.

Control Group

The Control Group provides computer control for an equipment group, processes target detections to develop and maintain a track file, and interfaces with the specific weapon system being used. The Control Group normally consists of the following equipment: a computer, data terminal set, magnetic tape unit, and test set.

Support Systems

The equipment we discussed above composes the core of the radar system. To operate properly and efficiently, it requires a certain amount of support

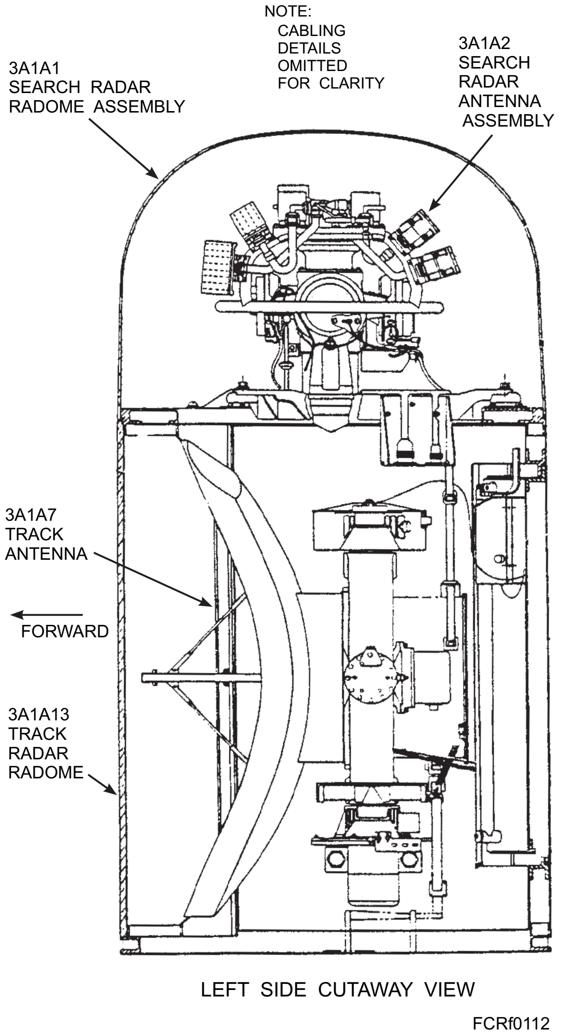

Figure 1-12.—Example of a search and track radome.

equipment. Examples of such equipment include power supplies (some also have frequency converters), chilled water systems, and dry air systems. Although your radar system normally receives 440 VAC directly from the ship's primary power source, it has other voltage requirements that may be stepped up, stepped down, or converted in order to make the radar fully operational. High-voltage amplifiers and peripheral equipment associated with producing RF energy create tremendous amounts of heat. Chilled water systems remove excessive heat from such equipment. Cooling systems may be either liquid-to-liquid or liquid-to-air types that use either sea water, or chilled water provided by the ship itself. Another important support system is the dry air system. Dry air is used for keeping the internal part of the waveguide assembly moisture free and to aid in properly conducting the RF energy being transmitted. The dry air may be either air taken from ship spaces and circulated through various filters or dehydrated air provided by the ship. Some systems use a special gas for their waveguides. An example of this is the Mk 92 Fire Control System, which uses the gas SF_6 for its Continuous Wave Illumination (CWI) mode.

These are very important support systems to your radar. As you know, any system is only as good as its weakest link. Therefore, you must be sure to maintain the support equipment as required by the equipment's technical manuals and maintenance instructions.

Stable Elements

Hitting a target on a regular basis requires that the gun or launcher be stable in relation to the target. Ideally, the platform on which the gun or launcher is mounted is stable throughout the target acquisition and destruction cycle. Unfortunately Navy ships, on which the guns and launchers are mounted, are seldom stable. In even the calmest sea, they pitch and roll to some extent. The solution lies in stabilizing the guns and launchers while the ship continues to pitch and roll. This is done with gyroscopes (gyros) installed in the fire control systems.

Gyros provide a stable platform, called the *horizontal plane*, as an unvarying reference from which the fire control problem is computed. The basic fundamentals and functions of gyros are covered in NEETS Module 15—*Principles of Synchros, Servos, and Gyros,* NAVEDTRA 14187.

In fire control, we call the stabilizing unit a *stable element*. As its name implies, the stable element uses a stabilizing gyro. The stabilizing gyro is also the primary reference for navigation of the ship. It gives the ship a true North reference for all navigational equipment. The WSN-2 or WSN-5 are examples of stabilizing gyros used in today's ships. The maintenance and operation of these gyros is the responsibility of the Interior Communications (IC) technicians. Figure 1-13 shows a phantom view of a gyro you might see on your ship.

The primary purpose of the stable element for fire control equipment is to measure accurately any deviation of the reference element (antenna, director, launcher, etc.) from the horizontal plane. Deviation measurements are sent to the fire control computer to create a stationary foundation from which to solve the fire control problem. They are also sent to the gun director, radar antenna, or optical equipment, depending upon the fire control system, to stabilize these units of the fire control system.

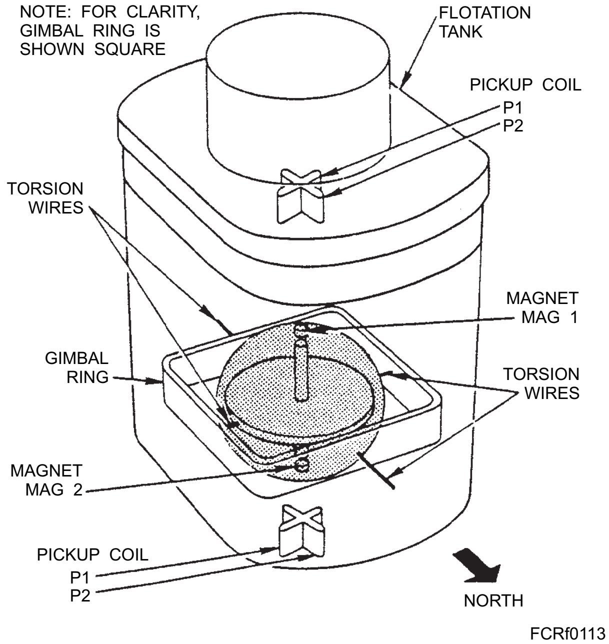

Figure 1-13.—Phantom view of a gyro.

TYPES OF RADAR SYSTEMS

Because of different design parameters, no single radar set can perform all the many radar functions required for military use. The large number of radar systems used by the military has forced the development of a joint-services classification system for accurate identification of radars. Radar systems are usually classified according to their specific function and installation vehicle. The joint-service standardized classification system divides these broad categories for more precise identification.

Since no single radar system can fulfill all the requirements of modern warfare, most modern warships, aircraft, and shore installations have several radar sets, each performing a specific function. A shipboard radar installation may include surface-search and navigation radars, a 3D radar, an air-search radar, and various fire-control radars.

Figure 1-14 is a listing of equipment identification indicators. You can use this table and the radar nomenclature to identify the parameters of a particular radar set. The example given explains the equipment indicators for the AN/SPY-1A radar system.

The letters AN were originally adopted by the Joint Army-Navy Nomenclature System, also known as the AN system, to easily classify all military electronic equipment. In 1985, Military Standard MIL-STD-196D changed the name of the Joint Army-Navy Nomenclature System to the "Joint Electronics Type Designation System (JETDS)", but the letters AN are still used in identifying military electronics equipment.

AIR-SEARCH RADAR

The primary function of an air-search radar is to maintain a 360-degree surveillance from the surface to high altitudes and to detect and determine ranges and bearings of aircraft targets over relatively large areas.

The following are some uses of an air-search radar:

- Give early warning of approaching enemy aircraft and missiles, by providing the direction from which an attack could come. This allows time to bring antiaircraft defenses to the proper degree of readiness and to launch fighters if an air attack is imminent.
- Observe constantly the movement of enemy aircraft. When it detects an enemy aircraft, guide combat air patrol (CAP) aircraft to a position suitable for an intercept.
- Provide security against attacks at night and during times of poor visibility.
- Provide information for aircraft control during operations that require a specific geographic track (such as an antisubmarine barrier or a search and rescue pattern).

Together, surface- and air-search radars provide a good early-warning system. However, the ship must be able to determine altitude to effectively intercept any air target. This requires the use of another type of radar.

MULTI-DIMENSIONAL RADAR

The primary function of a multi-dimensional radar is to compute accurate ranges, bearings, and altitudes of targets detected by an air-search radar. This information is used to direct fighter aircraft during interception of air targets.

The multi-dimensional radar is different from the air-search radar in that it has a higher transmitting frequency, higher output power, and a much narrower vertical beamwidth. In addition, it requires a stabilized antenna for altitude accuracy.

The following are some applications of a multi-dimensional radar:

- Obtain range, bearing, and altitude data on enemy aircraft and missiles to assist in the guidance of CAP aircraft.

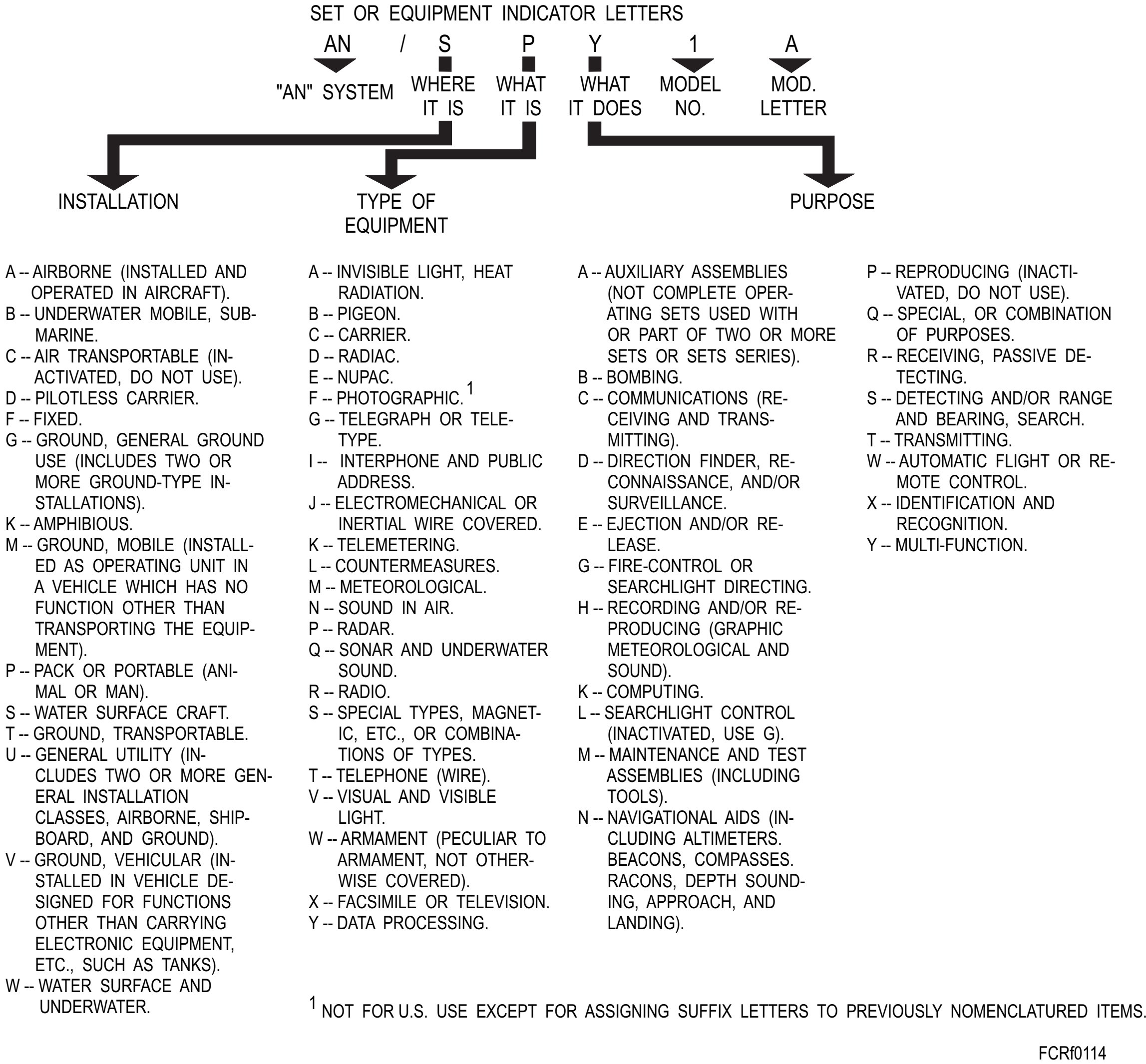

Figure 1-14.—AN equipment indicator system.

- Provide precise range, bearing, and height information for fast and accurate initial positioning of fire-control tracking radars.
- Detect low-flying aircraft.
- Determine the range to distant landmasses.
- Track aircraft over land.
- Detect certain weather phenomena.
- Track weather balloons.

The modern warship has several radars. Each radar is designed to fulfill a particular need, but it may also be capable of performing other functions. For example, most multi-dimensional radars can be used as secondary air-search radars; in emergencies, fire-control radars have served as surface-search radars. A multi-dimensional air-search radar is shown in figure 1-15.

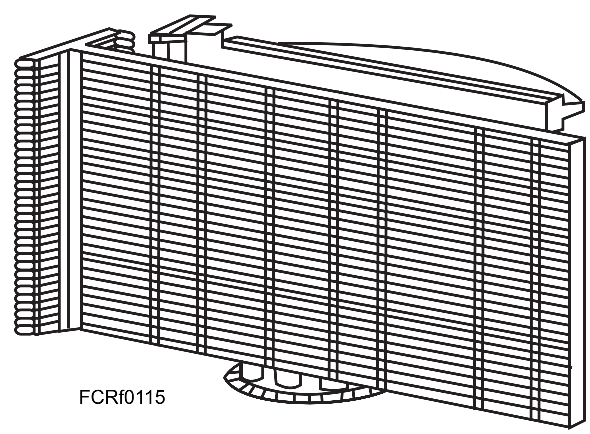

Figure 1-15.—Multi-dimensional (3-D) radar.

MISSILE GUIDANCE RADAR

The purpose of a guidance subsystem is to direct the missile to target intercept regardless of whether or not the target takes deliberate evasive action. The guidance function may be based on information provided by a signal from the target, information sent from the launching ship, or both. Every missile guidance system consists of two separate systems—an attitude control system and a flight path control system. The attitude control system maintains the missile in the desired attitude on the ordered flight path by controlling it in pitch, roll, and yaw (fig. 1-16). This action, along with the thrust of the rocket motor, keeps the missile in stabilized flight. The flight path control system guides the missile to its designated target. This is done by determining the flight path errors, generating the necessary orders needed to correct these errors, and sending these orders to the missile's control subsystem. The control subsystem exercises control in such a way that a suitable flight path is achieved and maintained. The operation of the guidance and control subsystems is based on the closed-loop or servo principle (fig. 1-17). The control units make corrective adjustments to the missile control surfaces when a guidance error is present. The control units also adjust the wings or fins to stabilize the missile in roll, pitch, and yaw. Guidance and stabilization are two separate processes, although they occur simultaneously.

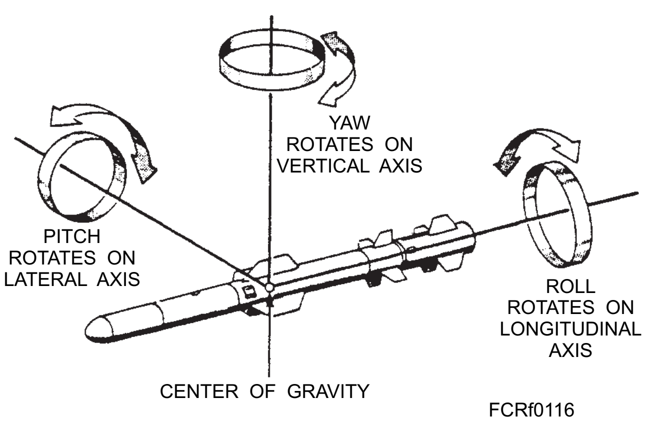

Figure 1-16.—Missile axes: pitch, roll, yaw.

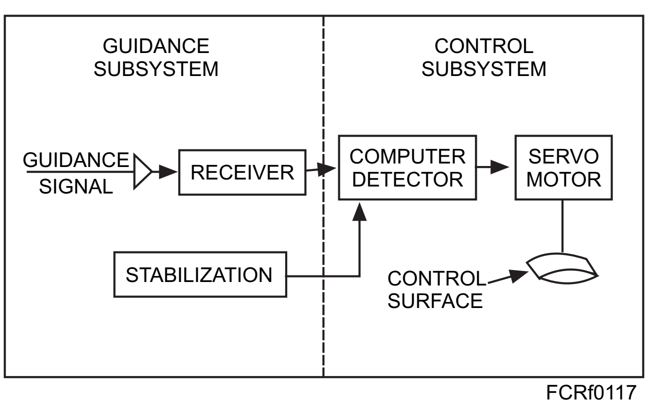

Figure 1-17.—Basic missile guidance and control systems.

Phases of Guidance

Missile guidance is generally divided into three phases (fig. 1-18). As indicated in the figure (view A), the three phases are *boost, midcourse,* and *terminal.* STANDARD SM-2 missiles (MR & ER) use all three of these phases. Not all missiles, however, go through the three phases. As shown in figure 1-18 (view B), some missiles (STANDARD SM-1, SEASPARROW) do not use midcourse guidance. With that thought in mind, let's examine each phase, beginning with boost.

INITIAL (BOOST) PHASE.—Navy surface-launched missiles are boosted to flight speed by the booster component (which is not always a separate component) of the propulsion system. The boost period lasts from the time the missile leaves the launcher until the booster burns up its fuel. In missiles with separate boosters, the booster drops away from the missile at burnout (fig. 1-18, view A). Discarding the burnt-out booster shell reduces the drag on the missile and enables the missile to travel farther. SMS missiles with separate boosters are the STANDARD SM-2 and HARPOON.

The problems of the initial (boost) phase and the methods of solving them vary for different missiles. The method of launch is also a factor. The basic purposes, however, are the same. The missile can be either pre-programmed or physically aimed in a specific direction on orders from the fire control computer. This establishes the line of fire (trajectory or flight path) along which the missile must fly during the boosted portion of its flight. At the end of the boost period, the missile must be at a precalculated point.

There are several reasons why the boost phase is important. If the missile is a homing missile, it must "look" in a predetermined direction toward the target. The fire control computer (on the ship) calculates this predicted target position on the basis of where the missile should be at the end of the boost period. Before launch, this information is fed into the missile.

When a beam-riding missile reaches the end of its boosted period, it must be in a position where it can be captured by a radar guidance beam. If the missile does not fly along the prescribed launching trajectory as accurately as possible, it will not be in position to acquire the radar guidance beam and continue its flight to the target. The boost phase guidance system keeps the missile heading exactly as it was at launch. This is primarily a stabilizing function.

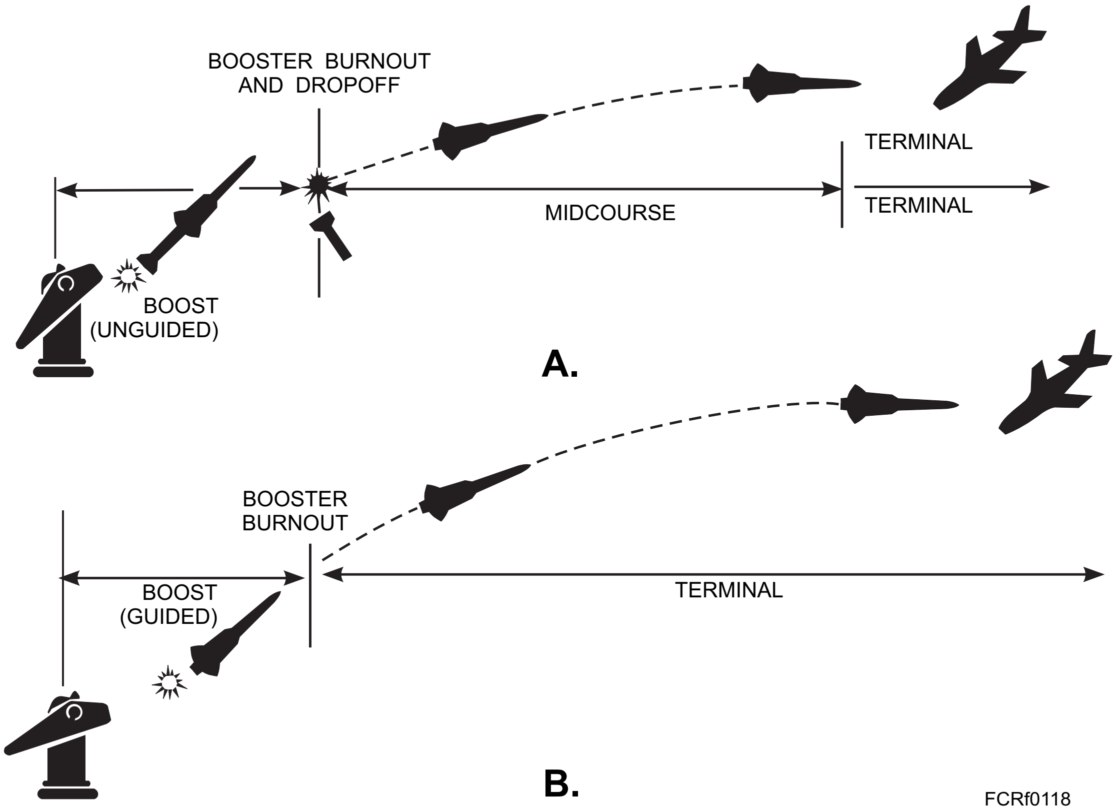

Figure 1-18.—Guidance phases of missile flight.

During the boost phase of some missiles, the missile's guidance system and the control surfaces are locked in position. The locked control surfaces function in much the same manner as do the tail feathers of a dart or arrow. They provide stability and cause the missile to fly in a straight line.

MIDCOURSE PHASE.—Not all guided missiles have a midcourse phase; but when present, it is often the longest in both time and distance. During this part of flight, changes may be needed to bring the missile onto the desired course and to make certain that it stays on that course. In most cases, midcourse guidance is used to put the missile near the target, where the final phase of guidance can take control. The HARPOON and STANDARD SM-2 missiles use a midcourse phase of guidance.

TERMINAL PHASE.—The terminal or final phase is of great importance. The last phase of missile guidance must have a high degree of accuracy, as well as fast response to guidance signals to ensure an intercept. Near the end of the flight, the missile may be required to maneuver to its maximum capability in order to make the sharp turns needed to overtake and hit a fast-moving, evasive target. In some missiles, maneuvers are limited during the early part of the terminal phase. As the missile gets closer to the target, it becomes more responsive to the detected error signals. In this way, it avoids excessive maneuvers during the first part of terminal phase.

Types of Guidance

As we mentioned earlier, missiles have a path control system and an attitude control system. Guidance systems are usually classified according to their path control system, since many missiles use the same type of attitude control. The type of attitude control used in the fleet is **inertial**. The following is a discussion of the types of path control (guidance) in use in SMS missiles.

INERTIAL GUIDANCE.—An inertial guidance system is one that is designed to fly a predetermined path. The missile is controlled by self-contained automatic devices called *accelerometers*.

Accelerometers are inertial devices that measure accelerations. In missile control, they measure the vertical, lateral, and longitudinal accelerations of the controlled missile (fig. 1-19). Although there may not be contact between the launching site and the missile after launch, the missile is able to make corrections to its flight path with amazing precision.

During flight, unpredictable outside forces, such as wind, work on the missile, causing changes in speed

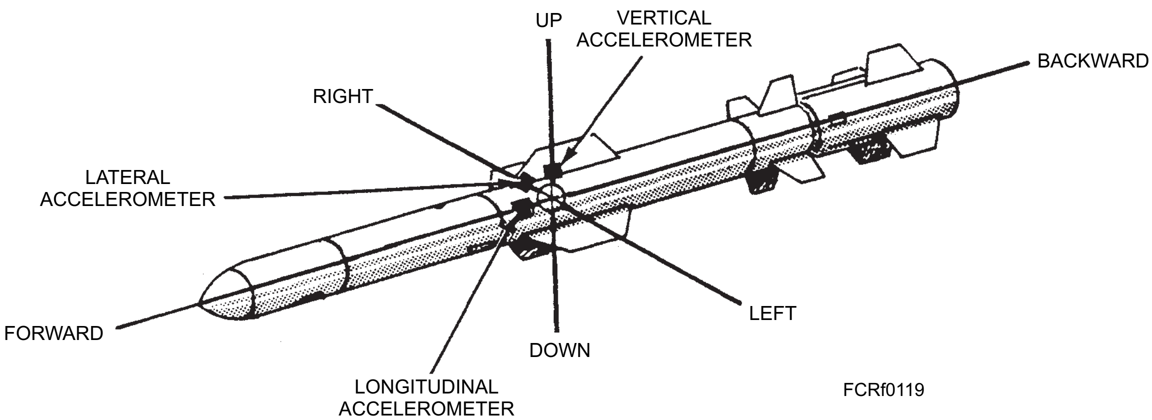

Figure 1-19.—Accelerometers in a guided missile.

commands. These commands are transmitted to the missile by varying the characteristics of the missile tracking or guidance beam, or by the use of a separate radio uplink transmitter.

BEAM-RIDER GUIDANCE.—A beam-rider guidance system is a type of command guidance in which the missile seeks out the center of a controlled directional energy beam. Normally, this is a narrow radar beam. The missile's guidance system receives information concerning the position of the missile within the beam. It interprets the information and generates its own correction signals, which keep the missile in the center of the beam. The fire control radar keeps the beam pointed at the target and the missile "rides" the beam to the target.

Figure 1-20 (view B) illustrates a simple beam-rider guidance system. As the beam spreads out, it is more difficult for the missile to sense and remain in the center of the beam. For this reason, the accuracy of the beam-rider decreases as the range between the missile and the ship increases. If the target is crossing (not heading directly at the firing ship), the missile must follow a continually changing path. This may cause excessive maneuvering, which reduces the missile's speed and range. Beam-riders, therefore, are effective against only short- and medium-range incoming targets.

HOMING GUIDANCE.—Homing guidance systems control the path of the missile by means of a device in the missile that detects and reacts to some distinguishing feature of (or signal from) the target. This may be in the form of light, radio, heat, sound waves, or even a magnetic field. The homing missiles use radar or RF waves to locate the target while air-to-air missiles sometimes use infrared (heat) waves.

Since the system tracks a characteristic of the target or energy reflecting off the target, contact between the missile and target is established and maintained. The missile derives guidance error signals based on its position relative to the target. This makes homing the most accurate type of guidance system, which is of great importance against moving air targets. Homing guidance methods are normally divided into three types:, active homing, semi-active homing, and passive homing (fig. 1-21).

Active Homing.—With active homing, the missile contains both a radar transmitter and a receiver. The transmitter radiates RF energy in the direction of the target (fig. 1-21, view A). The RF energy strikes the target and is reflected back to the missile. (This process is referred to as "illuminating the target.") The missile seeker (receiving) antenna detects the reflected energy and provides it as an input to the missile guidance system. The guidance system processes the input, usually called the homing error signal, and develops target tracking and missile control information. Missile control causes the missile to fly a desired flight path.

The effective range of the missile transmitter is somewhat limited because of its size (power output). For this reason, relatively long-range missiles, such as HARPOON, do not switch to active guidance until after midcourse guidance has positioned the missile so that the transmitter is within its effective range.

Semiactive Homing.—In a semiactive homing system, the target is illuminated by a transmitter (an illuminator) on the launching site (fig. 1-21, view B). As with active homing, the transmitted RF is reflected by the target and picked up by the missile's receiver. The fact that the transmitter's size is not limited, as with active homing, allows a much greater range.

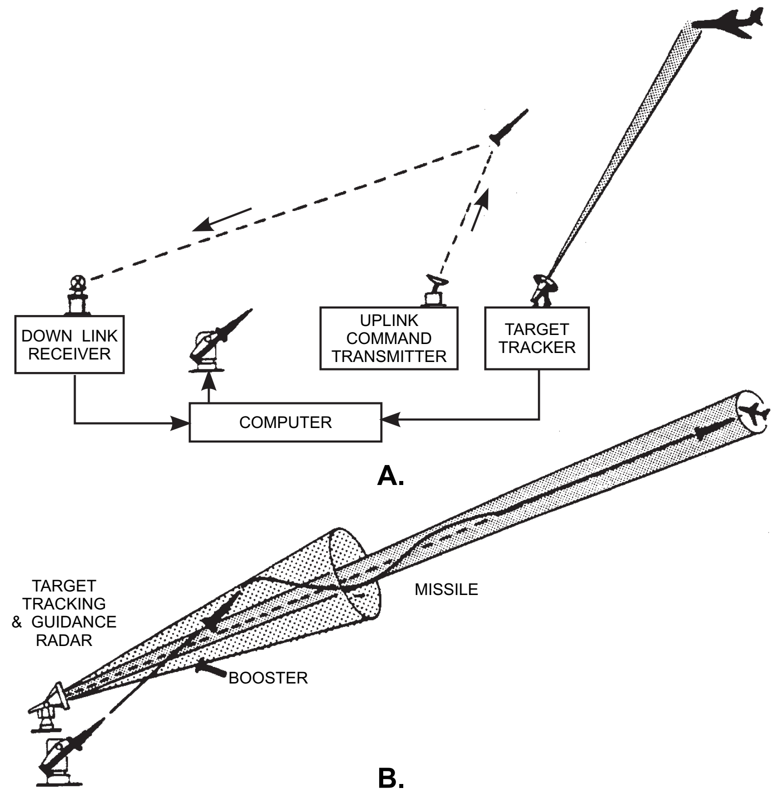

Figure 1-20.—Simplified command guidance systems: A. Radar/radio command; B. Beam rider.

The missile, throughout its flight, is between the target and the radar that illuminates the target. It will receive radiation from the launching ship, as well as reflections from the target. The missile must therefore have some means of distinguishing between the two signals, so that it can home on the target rather than on the launching ship. This can be done in several ways. For example, a highly directional antenna may be mounted in the nose of the missile; or the Doppler principle may be used to distinguish between the transmitter signal and the target echoes. Since the missile is receding from the transmitter and approaching the target, the echo signals will be of a higher frequency. Most SMS missiles use both of these methods.

A drawback of this system is that the shipboard illumination is not free to engage another target while the missile is in flight. STANDARD SM-1 and SEA-SPARROW all use semi-active homing as their primary guidance; they do not use midcourse guidance. The STANDARD SM-2 uses midcourse guidance, and then semi-active homing only for terminal guidance (fig. 1-20, view A). As a result, the SM-2 needs illumination from the ship only for the last few seconds of flight.

Passive Homing.—Passive homing requires that the target be a source of radiated energy (fig. 1-21, view C). Typical forms of energy used in passive homing are heat, light, and RF energy. One of the most common uses of passive homing is with air-to-air missiles that use heat-sensing devices. It is also used with missiles that home on RF energy that originates at the target (ships, aircraft, shore-based radar, and so forth). An example of this is the STANDARD ARM (anti-radiation missile) used for both air-to-surface and surface-to-surface engagements. An advantage of this type of homing is that the target cannot detect an attack because the target is not illuminated.

Several missiles that normally use other homing methods (active or semi-active) are capable of switching to the passive home-on-jamming (HOJ) mode in a countermeasure environment. That is, if the target detects that it is being illuminated by an active or semiactive guidance radar and initiates jamming (RF interference), the missile will home on the jamming signal if it is unable to maintain track on the reflected illumination signal.

Tracking Radar/Fire-Control Radar

Radar that provides continuous positional data is called tracking radar. Most tracking radar systems used

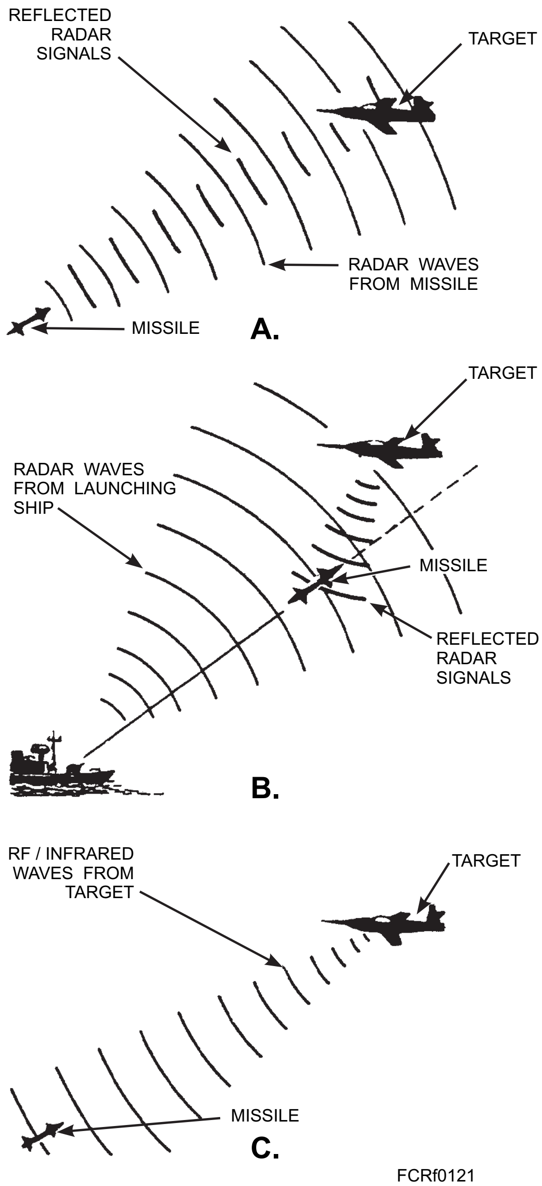

Figure 1-21.—Homing guidance: A. Active homing; B. Semiactive homing; C. Passive homing.

by the military are also called fire-control radars, the two names being interchangeable. A fire-control tracking radar system produces a very narrow, circular beam.

PHASES OF RADAR OPERATION

The three sequential phases of radar operation (designation, acquisition, and track) are often referred to as modes and are common to the target-processing sequence of most fire-control radars.

Designation Phase

During the designation phase, the fire-control radar is directed to the general location of the target.

Acquisition Phase

The fire-control radar switches to the acquisition phase once its beam is in the general vicinity of the target. During this phase, the radar system searches in the designated area in a predetermined search pattern until it either locates the target or is redesignated.

Track Phase

The fire-control radar enters into the track phase when it locates the target. The radar system locks on to the target during this phase.

Typical fire-control radar characteristics include high pulse-repetition frequency, a very narrow pulsewidth, and a very narrow beamwidth. A typical fire-control antenna is shown in figure 1-22.

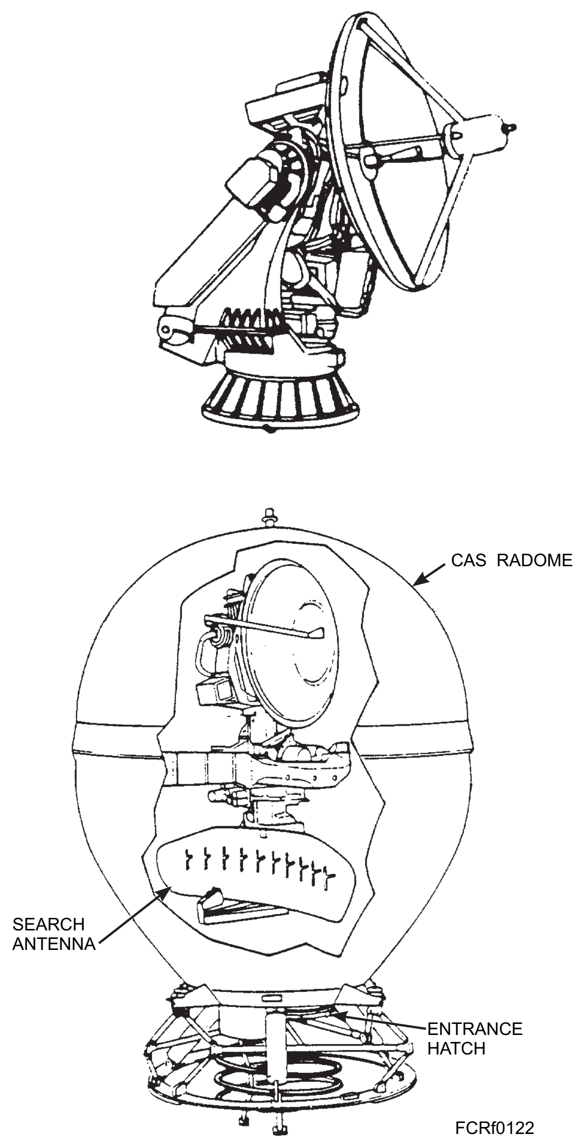

Figure 1-22.—Typical fire-control radar.

Detect-to-Engage Sequence

The basic sequence can be divided into six fundamental operations: detection, acquisition and tracking, prediction, launcher/gun positioning, guidance (missiles), and evaluation (intercept and target destruction). Figure 1-23 illustrates the fire control problem sequence.

DETECTION.—In this phase, the radar looks for a target. After the radar (usually a search radar) detects a target, the system obtains precise target position information. This information can be provided by the same source that detected the target, or it can be provided from some other source, such as another radar. In the majority of the cases, a second radar, a fire control radar, is used.

The search radar establishes the target's initial position and transmits this information to the designated fire control system.

ACQUISITION AND TRACKING.—During this phase, the fire control radar director/antenna is aligned with the search radar's target position information until it locks on the reflected target signal (acquisition). Either an operator or an automatic control circuit maintains that alignment (track) while the ship and target are moving. In this way, continuous, accurate target position information is available to the weapon system for processing. Not only is the continuous present position of the target obtained, but its movement (course and speed) is also determined.

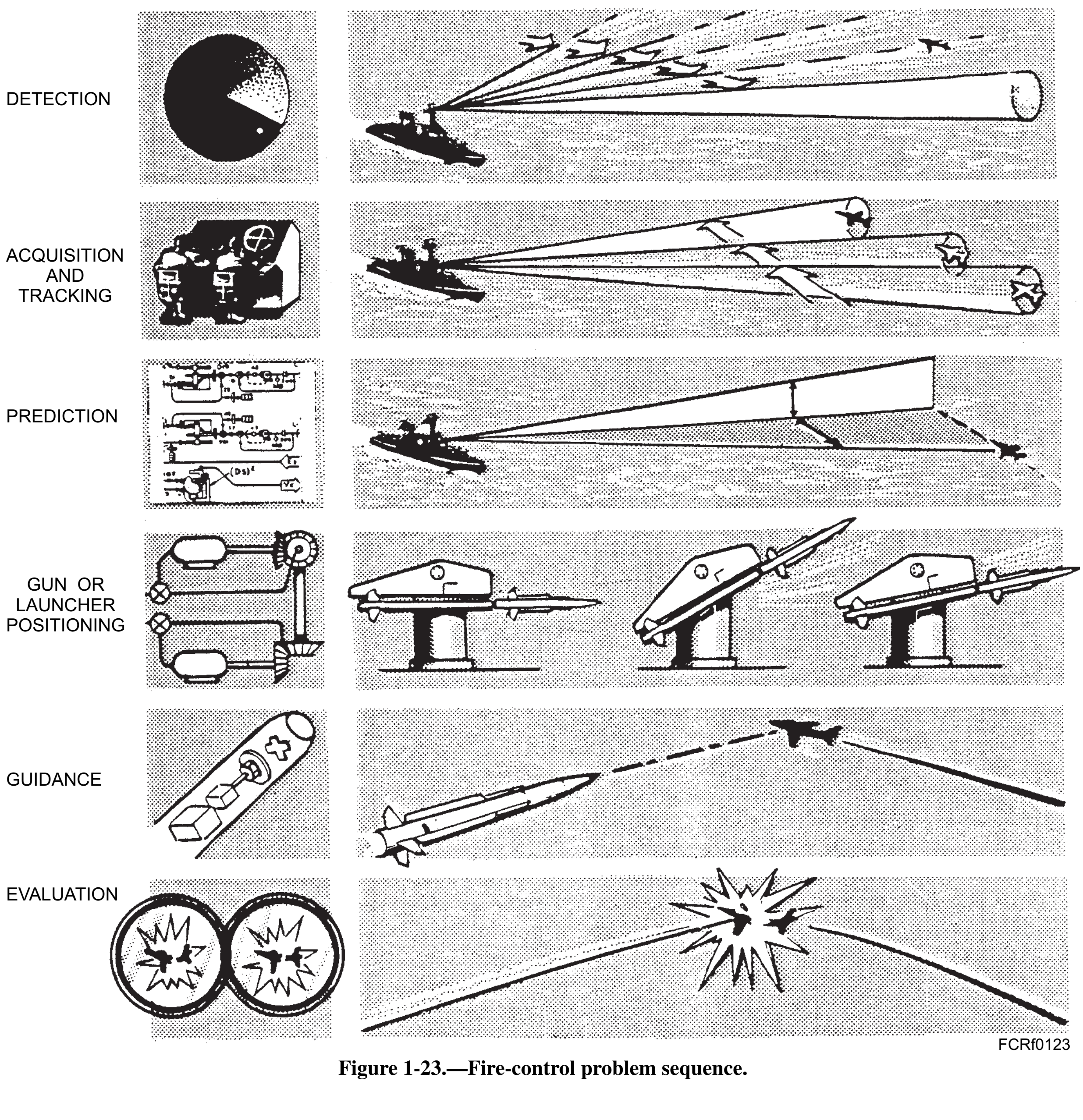

Figure 1-23.—Fire-control problem sequence.

Data other than target data is equally important for weapon flight path (trajectory) determination. Wind, for example, could blow the weapon off its flight path. Appropriate corrections would require that wind direction and velocity be determined. The course and speed of the launching ship and its motion, because of the sea (pitch and roll), are also important considerations. If this type of data is not included in the flight path determinations, it could cause large errors in the flight path (trajectory).

Data of this nature, along with target data, is transmitted to the fire control system's computer. The computer performs the necessary calculations for computing the launcher or gun mount position angles and the weapon's flight path.

After target detection and target acquisition have occurred, the fire control system provides three operations for the tracking, computation (prediction), and positioning functions.

The first operation tracks the target and provides all necessary data on the target. The fire control radar performs this function by establishing a tracking Line Of Sight (LOS) along which it receives the returned or reflected energy from the target. It also provides accurate range data.

Since the speed of the propagated RF energy is about 186,000 miles per second (the same as the speed of light), and since the target ranges involved are relatively small, the time for the energy to travel to and from the target can be considered as instantaneous. Therefore, the radar indications of the target can be considered as instantaneous, present-target positions.

PREDICTION.—The second operation of the fire control problem that must be performed is the computation of the gun/launcher positioning angle (line of fire) and the weapon flight path trajectory. This operation consists of two parts. First, the system processes received data into a usable form. Then the fire control computer performs arithmetic operations to predict the future position of the target.

LAUNCHER/GUN POSITIONING.—The third operation that must be performed is the positioning of the gun/launcher, based on the calculated line of fire to the future target position. This amounts to using the gun/launcher drive mechanism to offset the gun/launcher axis from the LOS by the amount of the predicted lead angle. In some cases, the missile is positioned (guided) in flight by the fire control system.

GUIDANCE (MISSILES).—For the Guided Missile Fire Control System (GMFCS), additional functions must be performed during the time the missile is in flight. Prior to launching, the fire control computer performs certain computations to provide the missile with information about the target and its own flight path. If the target maneuvers during the missile's flight, the computer can send course correction data to the missile via the fire control radar or the missile can correct itself.

EVALUATION.—The fire control radar displays are used to evaluate the weapon's destruction of the target. If the missile misses the target or causes only minor damage, additional weapons can be used. In missile fire control, another missile is fired. In gun fire control, corrections are made to bring the fall of shot onto a target using the radar indicators, optical devices, or spotter corrections. Normally, a target will be fired at until it is evaluated as either destroyed or damaged to the point it is no longer a threat.

RADAR SYSTEMS IN TODAY'S NAVY

There are too many radar systems used in today's Navy to cover in this volume. However, table 1-2 provides an overview of the radars and sensors in use, by AN system designator, ship class, and related FC systems.

SUMMARY

Radio, detecting, and ranging (radar) uses radio frequency (RF) energy and a complex integration of computers, displays, and support equipment to detect a target. However, radar is just one type of sensor that is available to the modern Fire Controlman. Other types of sensors (e.g., infrared and optical) use different parts of the electromagnetic spectrum. It is important that you, as a modern Fire Controlman, understand the basic concepts of the sensors used on your ship and other ships in the Navy. These sensors play a key part in accomplishing the ship's mission. As sensor technology improves, the Fire Controlman of the future will be expected to have a broader spectrum of knowledge and experience in order to keep our Navy on the cutting edge of naval warfare.

Table 1-2.—Radar Systems in the U. S. Navy

Designator	Type	Ship Class	Range	Weapon/Function	Related FC System
SEARCH					
SPS 48 C/E/F	3D Air Search, phased array	CV/CVN, LHA, LCC, LHD	220 NM	Primary Search	SYS-1,SYS-2
SPS 52 C	3D Air Search	LHD	240 NM	Primary Search	SYS-1
FIRE CONTROL					
Mk 92 CAS (Combined Antenna System)	Fire Control, Track-While-Scan, Search	FFG	25 NM	Mk 75 Gun, SM-1 missiles	Part of Mk 92 FCS
Mk 95 radar	Fire Control, CW tracker, illuminator	DD (Spruance), CV/CVN	20 NM	SEASPARROW missiles	Mk 23 TAS, Part of Mk 91 FCS
SPG 51 D	Fire Control, pulse-doppler, COSRO tracker, CWI	DDG (Kidd)	100 NM	SM-1(MR) missiles, SM-2 missiles	Part of Mk 74 FCS
SPG 60	Fire Control	DD (Spruance), DDG (Kidd)	50 NM	SM-1/2 missiles, Mk 45 LWG	SPY-1, Mk 86 GFCS
SPG 62	Fire Control, CW, illuminator	DDG (Arleigh Burke), CG (Ticonderoga)	20 NM	SM-2 missiles	SPY-1, Part of Mk 99 FCS
SPQ 9 Series	Fire Control, Track-While-Scan, (Surface), pulse-doppler	DD (Spruance), DDG (Kidd), CG (Ticonderoga), LHA	20 NM	SM-1/2 missiles Mk 45 LWG	SPY-1 Mk 86 GFCS
STIR (Separate Target Illuminating Radar)	Fire Control, monopulse tracker-illuminator	FFG	50 NM	Mk 75 Gun, SM-1 missiles	Part of Mk 92 FCS
OTHER					
CIWS (Close-In Weapon System)	Combined (search and track), pulse-doppler	ALL	5 NM Search 1 NM track	Anti-ship missile and air defense	None
HF Surface Wave	FM CW	LSD	6-12 NM	Anti-ship missiles	Sea Skimmer missile Detection/Air (This radar is still in development)
Mk 23 TAS (Target Acquistion System)	Air search, CW, tracker/illuminator	DD (Spruance), CV/CVN, LCC, LHD, LHA, LPD 17	20 NM	SEASPARROW missiles	Part of Mk 91 FCS/Mk 95 Radar
SPY 1 Series	Multi-function, phased array	D for DDG (Arleigh Burke), D for CG (Ticonderoga)	>100 NM	SM-2 missiles; search, track, and missile guidance, Mk 45 LWG	AEGIS, Mk 34 GWS, Mk 86 GFCS, Mk 99 FCS

Table 1-2.—Radar Systems in the U.S. Navy—Continued

Designator	Type	Ship Class	Range	Weapon/Function	Related FC System
OTHER—Continued					
SSDS Mk 1 (Ship Self-Defense System)	Integrated use of multiple ship sensors	FFG, LHD, LSD, LPD 17, AOE 6	Range as per each sensor	CIWS/RAM, SLQ 32, SPS 49, SEASPARROW missiles	Mk 2 replaces NATO SEASPARROW with ESSM (Evolved SEASPARROW missile)
OPTRONICS SYSTEMS					
Optical Sighting System (OSS) or Remote Optical Sighting System (ROS)	Sensor/View finder	Arleigh Burke (DDG), Ticonderoga (CG)	20 km surface, 10 km air	Mk 45 LWG	MK 34 GWS, MK 86 GFCS
FLIR (Forward Looking Infra-red)	Sensor	All ships upgraded to Block 1B	Surface/Air	Mk 15 Mods 11-14	CIWS Block 1 B
TISS (Thermal Imaging Sensor System)	Sensor	Arleigh Burke (DDG), Ticonderoga (CG), AOE-6, CV/CVN, LPD-17, LSD-41, LHD/LKA, DDG 993, DD 963	55 kyd/air, 45 kyd surface	Mk 31 RAM (Rolling Airframe Missile), CIWS, SSDS	AEGIS, Mk 86 GFCS

CHAPTER 2

FIRE CONTROL SYSTEMS

LEARNING OBJECTIVES

Upon completing this chapter, you should be able to do the following:

1. Identify and describe search radar systems associated with fire control radar.
2. Identify and describe missile and gun fire control radar systems.
3. Identify and describe other related sensor systems associated with fire control radar.
4. Describe the detect-to-engage scenario.
5. Describe the fire control problem in relationship to the detect-to-engage scenario.
6. Identify and describe cruise missile systems.

INTRODUCTION

In the preceding chapter, you read about the basic principles of radar operation. You also read about the basic components of a radar system and their relationship to each other. This chapter deals with specific radar systems and terms associated with those systems. You must understand those terms to get the maximum benefit from the information contained in this chapter. If you don't have a good understanding of radar operation and theory, we suggest that you review the following Navy Electricity and Electronics Training Series (NEETS) modules: *Microwave Principles*, Module 11, NAVEDTRA 14183, and *Radar Principles*, Module 18, NAVEDTRA 14190. We also suggest that you refer to the *Functional Description* section in your own technical manuals for the specific operation of your radar equipment.

The Fire Controlman rating deals with a large number of different radar systems, but you will probably be trained in only one or two of these systems. To help you develop a broad understanding of Fire Control radar, we will first discuss the Fire Control radars and sensors used in the fleet today. We will do this by category: search radar, missile direction/illumination radar, multi-function radar, and optronics systems. Then we will give you an overview of upcoming developments in radar.

SEARCH RADAR

You may think the function of Fire Control radar is to lock on to and identify a specific hostile target to direct a weapon to destroy it. That is the function of *most* FC radars. However, most FC radars use a narrow beam to perform their function. This makes using FC radar for *locating* a target impractical, since a narrow beam can easily miss targets. Locating targets requires using a radar with a wide beam. Search radar has such a beam. Search radar provides long-range (200 nautical miles or more), 360-degree coverage. It can determine a target's range, bearing, and elevation, and can then hand over that information to the more accurate narrow-beamed FC radar. Some Fire Control systems have built-in search and track radar; others rely on completely separate search radar. In this section, we will cover the separate search radars you will see in the surface Navy. These are the AN/SPS-52C and the AN/SPS-48 series search radars.

AN/SPS-48 RADAR

The AN/SPS-48 radar is a complete system upgrade of the AN/SPS-52C including all component elements—transmitter, receiver, computer (radar and automatic detection and tracking), frequency synthesizer and height display indicator. Figure 2-1 shows an antenna for the SPS-48 radar on the USS *Nimitz* CVN-68 (see arrow).

Figure 2-1.—USS *Nimitz* (CVN-68).

The SPS-48 radar is a long-range, three-dimensional, air-search radar system that provides contact range, bearing, and height information to be displayed on consoles and workstations. It does this by using a frequency-scanning antenna, which emits a range of different frequencies in the E/F band. The SPS-48 radar has three power modes: high, medium, and low.

An upgrade was needed because the 52C radar's single elevation beam could not dwell long enough in any particular direction. To solve this problem, the 48 series uses a process that stacks nine beams (a train of nine pulses at different frequencies) into a pulse-group. The nine beams simultaneously scan a 5-degree elevation area, allowing the stack to cover 45 degrees of elevation.

Two versions of the SPS-48 are currently in use: the 48C and the latest version, the 48E. Maximum elevation has increased somewhat, 65 degrees versus 45 degrees for the 52C. The "E" version has twice the radiated power of the "48C," developed by reducing the sidelobes and increasing the peak power. Receiver sensitivity is increased and the 48E has a four-stage solid state transmitter. The main operating modes are as follows:

- EAC (Equal Angle Coverage)—The radar's energy is concentrated at a low angle.
- MEM (Maximum Energy Management)—Both high and medium power are regulated.
- AEM (Adaptive Energy Management)—Allows the radar to be adapted to a priority target radar cross section and a potential jamming environment.
- LOW-E (Low Elevation)—Gives priority to the lower beam groups and transmits them as a Doppler wave.

The radar can also transmit as a single steerable beam group or it can burn through jamming using a chirp pulse.

Radar video, converted to a digital format, is displayed on consoles to allow operators to perform manual radar search, detection and tracking functions. True bearing indications appear when the track position is displayed in relation to true north, rather than to ownship.

Variation in frequency tends to make this radar more resistant to jamming than if it were operated at a fixed frequency. This provides a solution to the blind speed problem ("blind speed" is the speed a target travels that is too fast for the radar to track it) in systems. Frequency scanning imposes some limitations because a large portion of the available frequency band is used for scanning rather than to increase the resolution of targets. It also requires that the receiver bandwidth be extremely wide or that the receiver be capable of shifting the bandwidth center with the transmitted frequency.

The radar provides accurate height data by factoring in the effects of pitch and roll of the ship and changing the transmitted frequency accordingly. The ship's gyro system provides the radar set with this pitch and roll data.

The AN/SPS-48 radar works with other onboard radar sensors through the SYS-1/SYS-2, as did the AN/SPS-52C. Search data from the AN/SPS-48 radar is sent to multiple weapon systems. These include the Mk 91 Fire Control System for the SEASPARROW missile system, the Mk 95 radar, the Mk 23 Target Acquisition System, the Close-In Weapon System, and the Rolling Airframe Missile (RAM) System.

The AN/SPS-48 search radar is found on board NIMITZ (CVN-68) (fig. 2-1), KITTY HAWK (CV-63)-, and ENTERPRISE (CVN-65)-class carriers, BLUE RIDGE (LCC)-class amphibious command ships, and WASP (LHD)- and TARAWA (LHA)-class amphibious assault ships.

MISSILE AND GUN FIRE CONTROL RADAR

Although you may be involved in the operation of search radar, the majority of your work will be with radar systems used to control the direction and fire of gun and missile systems. These radar systems are normally part of a larger system. They are called Gun Fire Control Systems (GFCS) or Missile Fire Control Systems (MFCS). Some systems may be able to control the fire of either guns or missiles. These are simply called Fire Control Systems (FCS). This section will look at the radar associated with these gun and missile fire control systems.

MK 7 AEGIS FIRE CONTROL SYSTEM RADAR

The Mk 7 AEGIS Weapon System is installed on ARLEIGH BURKE-class destroyers (fig. 2-2) and TICONDEROGA-class cruisers (fig. 2-3). The Mk 7 AEGIS system contains the SPY-1 radar system, the Mk 99 Missile Fire Control System (MFCS) and the Mk 86 Gun Fire Control System (GFCS) or the Mk 34 GWS (Gun Weapon System). We will discuss each of these systems briefly as they relate to their associated radar systems.

Figure 2-2.—ARLEIGH BURKE-class destroyer DDG-60 USS *Paul Hamilton*.

Figure 2-3.—TICONDEROGA-class cruisers *USS Lake Erie* CG-70.

AN/SPY-1 Radar

The latest technology in multi-function radar is found in the AN/SPY-1 series on TICONDEROGA-class cruisers and ARLEIGH BURKE-class destroyers. Ships that do not use the AN/SPY-1 are being upgraded to a system known as Ship Self-Defense System (SSDS). We will discuss SSDS in another section.

For more than four decades, the U.S. Navy has developed systems to protect itself from surface and air attacks. After the end of World War II, several generations of anti-ship missiles emerged as threats to the fleet. The first anti-ship missile to sink a combatant was a Soviet-built missile that sank an Israeli destroyer in October 1967. This threat was reconfirmed in April 1988 when two Iranian surface combatants fired on U.S. Navy ships and aircraft in the Persian Gulf. The resulting exchange of anti-ship missiles led to the destruction of an Iranian frigate and a corvette by U.S.-built Harpoon missiles.

The U.S. Navy's defense against this threat relied on a strategy of gun and missile coordinated defense. Guns were supplemented in the late fifties by the first generation of guided missiles in ships and aircraft. By the late sixties, although these missiles continued to perform well, there was still a need to improve missile technology to match the ever-changing threat. To counter the newer enemy missile threat, the Advanced Surface Missile System (ASMS) was developed. ASMS was re-named AEGIS (after the mythological shield of Zeus) in December 1969.

The AEGIS system was designed as a total weapon system, from "detection" to "kill." The heart of the AEGIS system is an advanced, automatic detect and track, multi-functional phased-array radar, the AN/SPY-1. This high-powered (four-megawatt) radar can perform search, track, and missile guidance functions simultaneously, with a capability of over 100 targets. The first system was installed on the test ship, USS *Norton Sound* (AVM-1) in 1973. Figure 2-4 shows the weapons and sensors on an AEGIS-class cruiser.

The system's core is a computer-based command and decision element. This interface enables the AEGIS combat system to operate simultaneously in anti-air warfare, anti-surface warfare, and anti-submarine warfare.

The AN/SPY-1 series radar system works with two fire control systems on AEGIS-class ships: the Mk 99 Missile Fire Control System and the Mk 86 Gun Fire Control System (part of the Mk 34 Gun Weapon System). The Mk 86 GFCS is also found on SPRUANCE-class destroyers and works with the Mk 91 Missile Fire Control System. We will discuss the Mk 91 MFCS in a later section.

Mk 99 Missile Fire Control System

The Mk 99 MFCS controls the loading and arming of the selected weapon, launches the weapon, and provides terminal guidance for AAW (Anti-Air Warfare) missiles. It also controls the target illumination for the terminal guidance of SM-2 Anti-Air missiles. The radar system associated with the Mk 99 MFCS is the missile illuminator AN/SPG-62.

AN/SPG-62 RADAR.—The AN/SPG-62 is I/J-Band fire control radar. The SPY-1 radar system detects and tracks targets and then points the SPG-62 toward the target, which in turn provides illumination for the terminal guidance of SM-2 missiles. Refer to chapter 1 for discussion on the different phases of missile guidance and the way radar is used for missile guidance. Remember that to track a target, you need a very narrow beam of RF energy. The narrower the beam, the more accurately you can tell if you have one target or multiple targets (this is called radar resolution). This narrow beam radar is normally a second radar that works with a primary search or track radar. The AN/SPG-62 illuminating radar works as a second radar with the AN/SPY-1 series radar. See figure 2-4 for the location of AN/SPG-62 on an AEGIS cruiser.

In addition to the Mk 99 MFCS, the AEGIS SPY-1 series radar works with the Gun Fire Control System Mk 86. The Mk 86 GFCS controls the fire of the Mk 45 5-inch gun.

Mk 86 Gun Fire Control System

The Mk 86 Gun Fire Control System (GFCS) provides ships of destroyer size and larger with an economical, versatile, lightweight, gun and missile fire control system that is effective against surface and air targets.

The Mk 86 Gun Fire Control System (GFCS) is the central sub-element of the Mk 34 Gun Weapons System (GWS) on AEGIS-class ships. It controls the ship's forward and aft 5"/54 caliber Mk 45 gun mounts (fig. 2-5) and can engage up to two targets simultaneously. The SPQ-9 series and Mk 23 TAS (Target Acquisition System) work together to provide control for Naval Gun Fire Support (NGFS), Submarine Warfare (SUW) and Anti-Air Warfare (AW) gun engagements. The Mk 86 GFCS also uses a

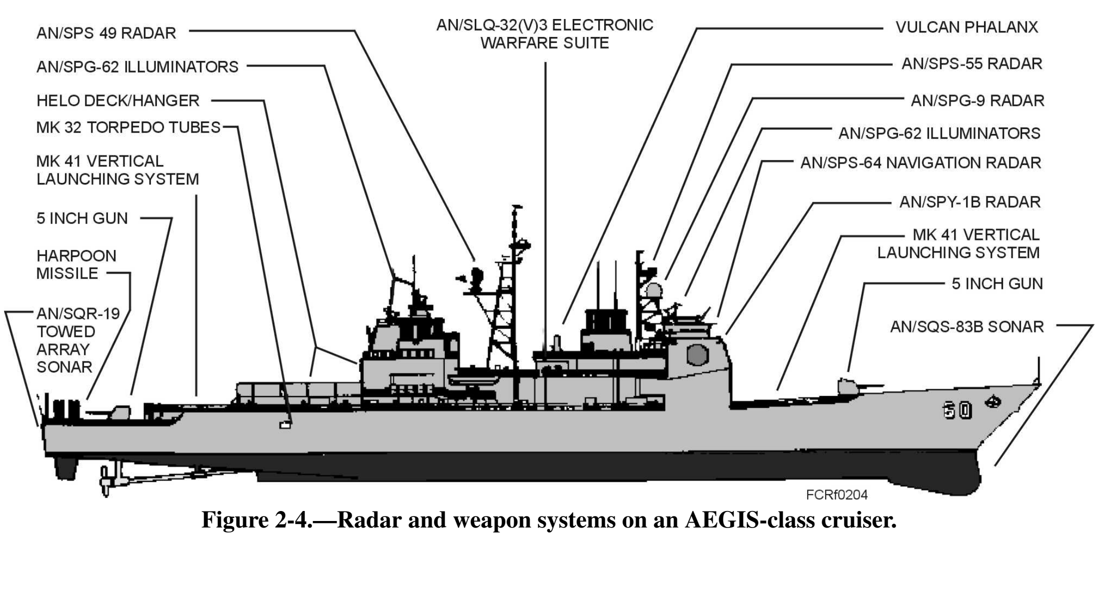

Figure 2-4.—Radar and weapon systems on an AEGIS-class cruiser.

Figure 2-5.—A 5"/54 Mk 45 gun mount.

Remote Optical Sighting system. This is a separate TV camera with a telephoto zoom lens mounted on the mast and each of the illuminating radars. The optical sighting system is known as ROS on the SPRUANCE-class destroyers and is mounted on the SPG-60 illumination radar. The Mk 34 GWS on AEGIS-class destroyers and cruisers uses the Mk 46 Mod 0 Optical Sight System on the SPG-62 illuminators.

The Mk 86 GFCS is the controlling element, where loading and firing orders originate. After an operator selects the GFCS mode, the system calculates ballistic gun orders. These orders can be modified to correct for environmental effects on ballistics. The GFCS conducts direct firing attacks against surface radar and optically tracked targets, as well as indirect firing during Naval Gun Fire Support (NGFS).

See figure 2-6 for a list of weapon systems and their sensors related to the Mk 86 GFCS on a SPRUANCE-class destroyer.

AN/SPQ-9 Radar

The AN/SPQ-9 Surface Surveillance and Tracking Radar, developed by Northrop Grumman Norden Systems, Melville, NY, is a track-while-scan radar used with the Mk-86 Gunfire Control system on surface combatants. Since it is a typical fire control radar, we will discuss it in more detail to help you understand the basic function of fire control radar.

The AN/SPQ-9B detects sea-skimming missiles at the horizon, even in heavy clutter, while simultaneously providing detection and tracking of surface targets and beacon responses. The AN/SPQ-9B is available as a stand-alone radar or as a replacement for the AN/SPQ-9 in the Mk 86 Gun Fire Control System, which will be integrated into the Mk 1 Ship Self-Defense System (SSDS).

The Radar Set AN/SPQ-9B is a high resolution, X-band narrow beam radar that provides both air and surface tracking information to standard plan position indicator (PPI) consoles. The AN/SPQ-9B scans the air and surface space near the horizon over 360 degrees in azimuth at 30 revolutions per minute (RPM). Real-time signal and data processing permit detection, acquisition, and simultaneous tracking of multiple targets. The AN/SPQ-9B provides raw and clear plot (processed) surface video, processed radar air synthetic video, gate video, beacon video synchro

Figure 2-6.—Weapons and sensors on a SPRUANCE-class destroyer.

signals indicating antenna relative azimuth, Azimuth Reference Pulses (ARP), and Azimuth Change Pulse (ACP). The radar will maintain its capabilities in the presence of clutter from the sea, rain, land, discrete objects, birds, chaff, and jamming.

The AN/SPQ-9B has three modes of operation: *air*, *surface*, and *beacon*. The air and surface modes have a submode for Combat Systems training. The AN/SPQ-9B complements high-altitude surveillance radar in detecting missiles approaching just above the sea surface. The system emits a one-degree beam that, at a range of approximately 10 nautical miles, can detect missiles at altitudes up to 500 feet. Since the beamwidth expands over distance, the maximum altitude will increase at greater ranges.

The *air mode* uses the Pulse-Doppler radar for detecting air targets. When the AN/SPQ-9B radar detects an air target and initiates a track, it will determine the target's position, speed, and heading. The air mode has a sector function called the Anti-Ship Missile Defense (ASMD). When the radar is radiating, the air mode is enabled continuously.

The *surface mode* generates a separate surface frequency and an independent pulse with a pulse repetition interval (PRI) associated with a range of 40,000 yards. In the surface mode, the AN/SPQ-9B radar has 360-degree scan coverage for surface targets. The radar displays raw and clear plot video, has a submode called Surface-Moving Target Indicator (MTI), and operates concurrently with the air mode. While the radar is in the radiate state, the surface mode is enabled continuously.

The *beacon mode* generates a separate beacon frequency and an independent pulse with a PRI having a range of 40,000 yards. The AN/SPQ-9B radar has 360-degree scan coverage for beacon targets. The received beacon video is sent to the console for display and distribution, while beacon track data is sent to the computer for processing. The AN/SPQ-9B beacon mode operates at the same time as the air and surface modes.

The ASMD Sector function allows the air mode to provide quick response detection of low-flying high-threat targets. Through this function, the radar automatically detects, tracks, and reports any targets entering the ASMD sector that require a reaction time of less than 30 seconds. The operator can select an ASMD azimuth sector width between five and 360 degrees and a range of up to 20 NMI. The ASMD sector function operates together with the air, surface, and beacon modes.

The Surface-MTI Submode allows the surface mode to cancel non-moving targets. The Surface-MTI azimuth sector width is operator selectable between a bearing width of five and 360 degrees, with the AN/SPQ-9B automatically displaying any targets with a relative speed exceeding 10 knots. The AN/SPQ-9B Radar Surface-MTI submode will operate concurrently with the air, surface, and beacon modes.

The AN/SPQ-9B is installed on ships and aircraft carriers in the following classes:

- CG-47 TOCONDEROGA-class cruisers (fig. 2-3)
- LHD-1 amphibious ships (fig. 2-2)
- LPD-17 SAN ANTONIO-class amphibious ships
- DD-963 SPRUANCE-class destroyers (fig. 2-6
- DDG-51 ARLEIGH BURKE-class destroyers (fig. 2-2)

The AN/SPQ-9 series radar also works with the SPY-1 series radar. SPQ-9 radar helps to control a number of weapons that include: SM-1/SM-2 missiles and the Mk 45 5"/54 gun.

Mk 23 Target Acquisition System (TAS)

The Mk 23 Target Acquisition System (TAS) is a detection, tracking, identification, threat evaluation, and weapon assignment system. It is used against high-speed, small cross-section targets that approach the ship from over the horizon at very low altitudes or from very high altitudes at near vertical angles. The TAS integrates a medium-range, two-dimensional, air-search radar subsystem, an IFF subsystem, a display subsystem, and a computer subsystem. This allows TAS to provide automatic or manual target detection and tracking, target identification, threat evaluation, and weapon assignment capabilities for engagement of air tracks. The Mk 23 TAS automatic detection and tracking radar is also an element of the Mk 91 Missile Fire Control system and is used on SPRUANCE-class destroyers, carriers, LHDs-, LHAs-, and the LPD-17 class amphibious assault ships. The Mk 91 MFCS and TAS control the SEASPARROW missile as their primary weapon. Figure 2-7 shows a Mk 29 box launcher for SEASPARROW missiles.

Figure 2-7.—MK 29 box launcher for SEASPARROW missiles.

MK 91 FIRE CONTROL SYSTEM

The Mk 91 NATO SEASPARROW Guided Missile Fire Control System (GMFCS) integrates the Mk 157 NATO SEASPARROW Surface Missile System (NSSMS) into the Ship Self-Defense System (SSDS) to provide an additional layer of ship missile defense. In this system, the Firing Officer Console and Radar Set Consoles are combined into a single Advanced Display System Console (AN/UYQ 70); the Signal Data Processor is modified; the Mk 157 Computer Signal Data Converter and the System Evaluation and Trainer (SEAT) are eliminated; and the microprocessor circuitry within the SSDS electronics is upgraded. This eliminates the limited input-output channel and computer processing deficiencies resident in the older Mk 57 NSSMS. The radar associated with the Mk 91 Fire Control System includes the Mk 95 illuminator, Mk 23 Target Acquisitioning System, and the AN/SPQ-9 series radar.

The Mk 95 illuminator is used exclusively with the NATO SEASPARROW GMFCS. It is an X-band tracker-illuminator on a Mk 78 director and works with the Mk 23 TAS. The Mk 91 Fire Control System and its associated radar systems are found on SPRUANCE-class destroyers, carriers, LHDs-, AOEs-, AORs-, and TARAWA-class amphibious assault ships.

Refer to figure 2-6 for the various weapons systems and radar associated with the Mk 86 and Mk 91 fire control systems on a SPRUANCE-class destroyer.

MK 92 FIRE CONTROL SYSTEM RADAR

The Mk 92 Fire Control System (FCS) provides FFG-7 class frigates (fig. 2-8) and other surface combatants with a fast reaction, high firepower, all-weather weapons control system for use against air and surface targets. The Mark 92's surface and air surveillance capability gives highly accurate gun and missile control against air and surface targets.

The Mark 92 fire control system, an American version of the WM-25 system designed in the Netherlands, was approved for service use in 1975. Introduction to the fleet and follow-on test and evaluation began in 1978. In 1981, an aggressive program to improve performance and reliability of the Mk 92 fire control system in clutter and electronic counter-measure environments was launched, with an at-sea evaluation aboard the USS *Estocin* completed in 1986. Following the evaluation, the upgraded system, identified as Mk 92 Mod 6 was installed in USS *Ingraham* (FFG-61). The Mk 92 Mod 6 will replace the Mod 2 systems in the fleet.

The Mk 92 Fire Control System (FCS) is deployed on board FFG-7 PERRY class ships in conjunction with the Mk 75 Naval Gun (fig. 2-9) and the Mk 13 Guided Missile Launching System (fig. 2-10). The Mk 92 FCS integrates target detection with multichannel antiair and antisurface missile and gun systems control, engaging up to four targets simultaneously. The Mk 92 "track-while-scan" radar uses the Combined Antenna System (CAS), which houses a search antenna and a tracker antenna inside a single egg-shaped randome (fig.2-8). A Separate Target

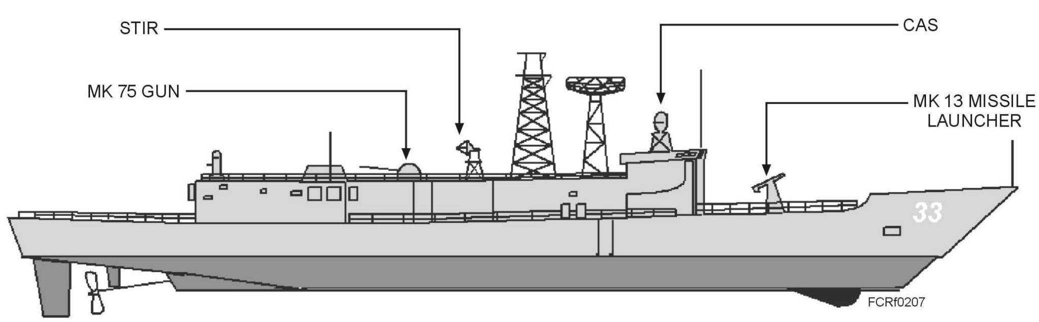

Figure 2-8.—Mk 92 fire control system on PERRY-class frigate.

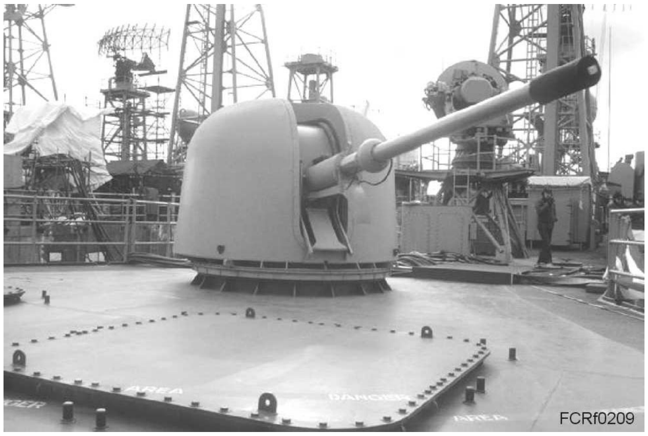

Figure 2-9.—Mk 75 naval gun system.

Figure 2-10.—Mk 13 guided missile launcher system.

Illumination Radar (STIR) (fig. 2-8) designed for the PERRY-class Mk 92 FCS application provides a large diameter antenna for target illumination at ranges beyond CAS capabilities.

MK 15 CLOSE-IN WEAPON SYSTEM

The Mk 15 Phalanx Close-In Weapon System (CIWS) is a stand-alone, quick-reaction time defense system that provides final defense against incoming air targets. CIWS will automatically engage anti-ship missiles and high-speed, low-level aircraft that penetrate the ship's primary defenses. As a stand-alone weapon system, CIWS automatically searches for, detects, tracks, evaluates for threat, fires at, and assesses kills of targets. A manual override function allows the operator to disengage a target, if necessary.

The search and track radar antennas are enclosed in a radome mounted on top of the gun assembly (see figure 2-11). All associated electronics for radar operations are enclosed within either the radome or the Electronics Enclosure (called the ELX). CIWS is operated remotely from either a Local Control Panel (LCP) or the Remote Control Panel (RCP) located in the Combat Information Center (CIC). It has two primary modes of operation: automatic and manual. In the automatic mode, the computer program determines the threat target, automatically engages the target, and performs the search-to-kill determination on its own. In the manual mode, the operator fires the gun after CIWS has identified the target as a threat and has given a "recommend fire" indication.

CIWS was developed in the late 1970's to defend against anti-ship cruise missiles. However, as the sophistication of cruise missiles increased, so did the sophistication of CIWS. Major changes to CIWS are referred to as "Block upgrades". The first upgrade, known as "Block 0," incorporated a standard rotating search antenna. Limitations of elevation in Block 0 lead to the next upgrade, Block 1. Block 1 provided improved elevation coverage and search sensitivity by using a phased-array antenna. A minor upgrade to

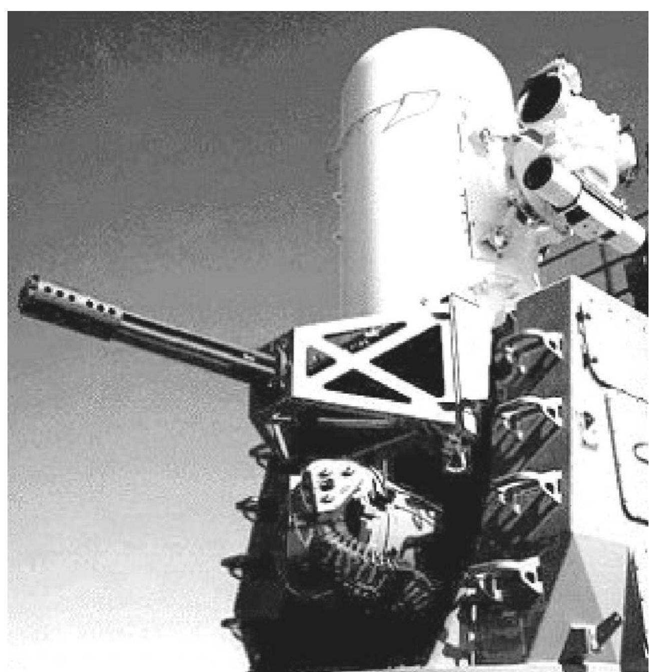

Figure 2-11.—Phalanx Block 1B.

Block 1, known as Block 1A, improved the processing power of the computer by incorporating a new high-order language. This upgrade gave CIWS the ability to (1) track maneuvering targets and (2) work with multiple weapons coordination. The next upgrade, Block 1B, enabled CIWS to engage surface targets. This upgrade is known as the Phalanx Surface Mode (PSUM). A special radar, Forward-Looking Infrared Radar (FLIR), was added to CIWS to detect small surface targets (i.e., patrol/torpedo boats) and low, slow, or hovering aircraft (i.e., helicopters). This radar is mounted on the side of the radome structure. FLIR can also help the radar system engage anti-ship cruise missiles. To detect targets day or night, CIWS Block 1B uses a thermal imager and advanced electro-optic angle tracking.

MK 31 Rolling Airframe Missile (RAM)

The RAM is a supersonic, lightweight, quick-reaction, fire-and-forget missile requiring no Illuminator, with no self-destruct capability, designed to destroy anti-ship cruise missiles (fig. 2-12). Its dual-mode passive RF and IR guidance requires no shipboard inputs after missile launch. Provides high firepower capability for engaging multiple threats simultaneously. The MK 44 Guided Missile Round Pack, and 21-cell MK 49 Guided Missile Launching System, comprise the MK 31 Guided Missile Weapon System. The weapon system has been designed for no shipboard dedicated sensors required. Numerous existing ship sensors can provide the required target information required to engage the anti-ship threat.

Figure 2-12.—RAM missile.

RAM Block 1

RAM is ready for the anticipated non-RF radiating anti-ship cruise missiles (ASCM's) of the future. The RAM Block 1 missile is designed to defeat tomorrow's ASCM's, while retaining the RF-to-IR guidance modes of the Block 0 RAM. Block 1 incorporates a new image-scanning seeker with the added capability of IR-all-the-way guidance, thus countering advanced anti-ship missiles that do not employ radar seekers. Block 1 also allows increased ECM, and severe IR background conditions.

SHIP SELF-DEFENSE SYSTEM (SSDS)

The principal air threat to US naval surface ships is a variety of highly capable anti-ship cruise missiles (ASCMs). These include subsonic (Mach 0.9) and supersonic (Mach 2+), and low altitude ASCMs. Detection, tracking, assessment, and engagement decisions must be made rapidly to defend against these threats, since the time from when an ASCM is initially detected until it is engaged is less than a minute. SSDS is designed to accomplish these defensive actions.

SSDS, consisting of software and commercial off-the-shelf (COTS) hardware, integrates and coordinates all of the existing sensors and weapons systems aboard a non-AEGIS ship to provide Quick Reaction Combat Capability (QRCC). (It will eventually be installed on board most classes of non-AEGIS ships.) SSDS, by providing a Local-Area Network (LAN), LAN access units (LAUs), special computer programs, and operator stations, automates the defense process, from the detect sequence through the engage sequence. This provides a quick response, multi-target engagement capability against anti-ship cruise missiles.

The entire combat system, including the sensors and weapons, is referred to as Quick Reaction Combat Capability (QRCC), with SSDS as the integrating element. Although SSDS broadens the ship's defensive capability, it is not intended to improve the performance of any sensor or weapon beyond its stand-alone performance. The primary advantage SSDS brings to the combat systems suite is the ability to coordinate both hard kill (gun and missile systems) and soft kill (decoys such as chaff) systems and to use them to their optimum tactical advantage.

The following systems represent the SSDS interfaces for a non-AEGIS ship:

- AN/Air Search Radar
- AN/Surface Search Radar
- AN/Electronic Warfare System
- Centralized Identification Friend or Foe (CIFF)
- Rolling Airframe Missile (RAM)
- Phalanx Close-in Weapon System (CIWS)
- Mk 36 Decoy Launching System (DLS)

SSDS options range from use as a tactical decision aid (up to the point of recommending when to engage with specific systems) to use as an automatic weapon system. SSDS will correlate target detections from individual radars, the electronic support measures (ESM) system, and the identification-friend or foe (IFF) system, combining these to build composite tracks on targets while identifying and prioritizing threats. Similarly, SSDS will expedite the assignment of weapons for threat engagement. It will provide a "recommend engage" display for operators or, if in automatic mode, will fire the weapons, transmit ECM, deploy chaff or a decoy, or provide some combination of these.

OPTRONICS SYSTEMS

As you have seen, the majority of sensor systems you will work with are of the RF type. That is, RF energy is transmitted via a complex system of components to detect and destroy a target. There are also other sensors used in today's Navy that use a different method of locating targets and helping in the direction of weapons. These systems use light or heat as a source for target detection. They are described as "Optronic" systems because they use light frequency rather than RF energy as a detecting element and a system of optical lenses for focusing a light source. An example of this type of system used in the Navy today is the Thermal Imaging Sensor System (TISS). It is representative of other similar optronics systems in use today.

THERMAL IMAGING SENSOR SYSTEM (TISS)

The Thermal Imaging Sensor System (TISS) is a shipboard electro-optical system that consists of a low-light television camera and an eye-safe laser rangefinder. The TISS director is designed to be mast mounted. The control console can be mounted in CIC or in the pilothouse. In addition to providing surface and air target data to combat systems, the TISS can also be used to detect mines and to provide good night identification and detection capabilities.

TISS was originally tested on board the USS *Ticonderoga* (CG-47) and later installed on the USS *Vicksburg* (CG-69) for her deployment to the Middle East in April 1997. TISS will initially be installed as a stand-alone system on deploying ships. As more units are completed, permanent installation and integration into the combat systems will become standard. Systems that use TISS are the Mk 86 Gun Fire Control System, CIWS, SSDS, and RAM.

UPCOMING DEVELOPMENTS IN RADAR

To keep pace with the approaching 21st century needs for multi-mission surface warships, the Navy is continually developing new technology that allows it to do more with less. We mention some of these developments, related to radar and sensors, below.

HIGH FREQUENCY SURFACE WAVE RADAR

High frequency surface wave radar is used to detect low-altitude missiles beyond the ship's horizon. The transmitting antennas are meandering-wave type units and are mounted on either side of the ship, near the bridge. The receivers are separate deck-edge or superstructure units. This radar uses an FMCW (Frequency Modulated-Continuous Wave) transmitter with a 50% duty cycle, with co-located transmit and receive antennas.

MULTI-FUNCTION RADAR

The new Multi-Function radar (MFR) will greatly enhance ship defense capability against modern air and missile threats in the littoral environment (areas close to shoreline). This system is based on solid-state, active-array radar technology that will provide search, detect, track, and weapon control functions while dramatically reducing manning and life-cycle costs associated with the multiple systems that perform these functions today. The MFR will be complemented by a new Volume Search Radar (VSR), which will provide timely cueing to MFR at long ranges and above the horizon.

INFRARED SEARCH AND TRACK (IRST)

The Infrared Search and Track (IRST) system is an integrated sensor designed to detect and report low-flying antiship cruise missiles by detecting their thermal heat plume or heat signature. IRST will continually scan the horizon and report any contacts to the ship's combat information center for tracking and engagement. The scanner is designed to search several degrees above and below the horizon but can be slewed manually to search for higher flying targets. IRST is a passive system providing bearing, elevation angle, and thermal intensity of a target. The system consists of a mast-mounted and stabilized scanner, below decks electronics, and a UYQ-70 operator's console.

DETECT TO ENGAGE SEQUENCE FOR FIRE CONTROL

This chapter has covered the radar systems you will see as an FC in the fleet today. You have been given a brief overview of the radar systems and their functions and uses. You have also learned the associated weapon systems and ship types associated with each radar system. Now that you have an understanding of these radar systems, you need to know how these systems are used in an actual combat scenario. The following section gives you an imaginary scenario of what might happen if you were to detect an enemy target, from beginning to end.

THE DETECT-TO-ENGAGE SEQUENCE

The international situation has deteriorated and the United States and Nation Q have suspended diplomatic relations. The ruler of Nation Q has threatened to annex the smaller countries bordering Nation Q and has threatened hostilities toward any country that tries to stop him. You are assigned to a guided missile cruiser that is a member of Battle Group Bravo, currently stationed approximately 300 nautical miles off the coast of Nation Q. The battle group commander has placed the Battle Group on alert by specifying the Warning Status as YELLOW in all warfare areas, meaning that hostilities are probable.

You are standing watch as the Tactical Action Officer (TAO) in the Combat Information Center (CIC), the nerve center for the ship's weapons systems. Dozens of displays indicate the activity of ships and aircraft near the Battle Group (fig. 2-13). As the TAO, you are responsible for the proper employment of the ship's weapons systems in the absence of the commanding officer. The time is 0200. You are in charge of a multi-million dollar weapon system and responsible for the lives and welfare of your shipmates.

Figure 2-13.—Display consoles in the Combat Information Center (CIC).

The relative quiet is shattered by an alarm on your Electronic Warfare (EW) equipment indicating the initial ***detection and identification*** of a possible incoming threat by your Electronic Support Measures (ESM) equipment. The wideband ESM receiver detects an electromagnetic emission on a bearing in the direction of Nation Q. Almost instantaneously the ESM equipment interprets the emitter's parameters and compares them with radar parameters stored in its memory. The information and a symbol indicating the emitter's approximate line of bearing from your ship are presented on a display screen. You notify the commanding officer of this development. Meanwhile, the information is transmitted to the rest of the Battle Group via radio data links.

Moments later, in another section of CIC, the ship's long-range two-dimensional air search radar is just beginning to pick up a faint return at its maximum range. The information from the air search radar coupled with the line of bearing from your ESM allows you to ***localize*** the contact and determine an accurate range and bearing. Information continues to arrive, as the ESM equipment ***classifies*** the J-band emission as belonging to a Nation Q attack aircraft capable of carrying anti-ship cruise missiles.

The contact continues inbound, headed toward the Battle Group. Within minutes, it is within range of your ship's three-dimensional search and track radar. The contact's bearing, range, and altitude are plotted to give an accurate course and speed. The range resolution of the pulse-compressed radar allows you to determine that the target is probably just one aircraft. You continue to ***track*** the contact as you ponder your next move.

As the aircraft approaches the outer edge of its air-launched cruise missile's (ALCM) range, the ESM operator reports that aircraft's radar sweep has changed from a search pattern to a single target track mode. This indicates imminent launch of a missile. According to the Rules of Engagement (ROE) in effect, you have determined hostile intent on the part of the target and should defend the ship against imminent attack. You inform your CIC team of your intentions, and ***select a weapon***, in this case a surface to air missile, to engage the target. You also inform the Anti-Air Warfare Commander of the indications of hostile intent, and he places you and the other ships in Air Warning Red, "attack in progress."

As the target closes to the maximum range of your weapon system, the fire control or tactical computer program, using target course and speed computes a predicted intercept point (PIP) inside the missile engagement envelope. This information and the report that the weapon system has locked-on the target is reported to you. You authorize "batteries release" and the missile is launched toward the PIP (fig. 2-14). As the missile speeds toward its target at Mach 2+, the ship's sensors continue to track both the aircraft and the missile. Guidance commands are sent to the missile to keep it on course.

Figure 2-14.—Missile launch from an AEGIS-class cruiser.

On board the enemy aircraft, the pilot is preparing to launch an ALCM when his ESM equipment indicates he is being engaged. This warning comes with but precious few seconds, as the missile enters the terminal phase of its guidance. In a desperate attempt to break the radar lock, the pilot uses evasive maneuvering. It's too late though. As the missile approaches its lethal "kill radius," the proximity fuze on the missile's warhead detonates the missile's explosive charge, sending fragments out in every direction, ***destroying or neutralizing*** the target (fig. 2-15). This information is confirmed by your ship's sensors. The radar continues to track that target as it falls into the sea and the ESM equipment goes silent.

THE FIRE CONTROL PROBLEM

The above scenario is not something out of a war novel, but rather an example of a possible engagement between a hostile force (the enemy attack aircraft) and a naval weapons system (the ship). This scenario illustrates the concept of the "detect-to-engage" sequence, which is an integral part of the modern Fire Control Problem. Although the scenario was one of a surface ship against an air target, every weapon system performs the same functions: ***target detection, resolution or localization, classification, tracking, weapon selection, and ultimately neutralization***. In

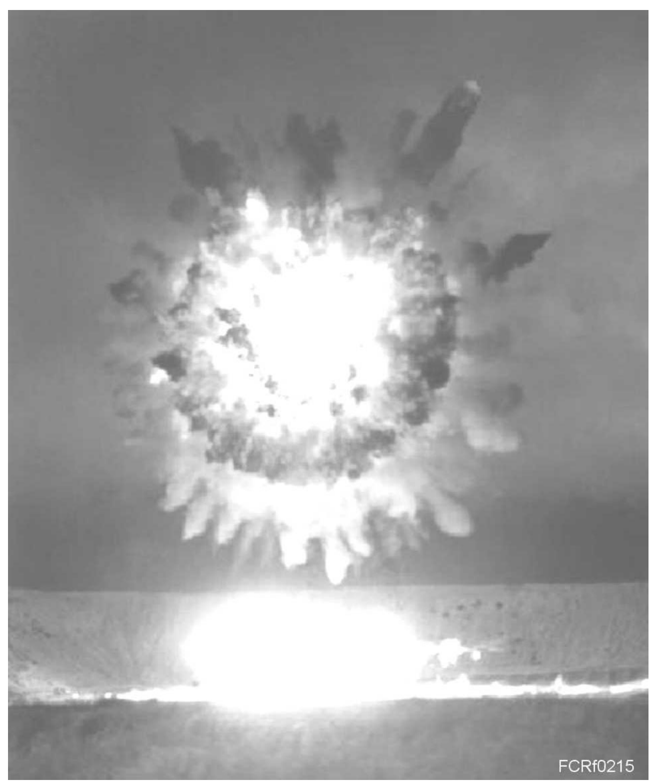

Figure 2-15.—Successful engagement of a missile.

warfare, these functions are performed by submarines, aircraft, tanks, and even Marine infantrymen. The target may be either stationary or mobile; it may travel in space, through the air, on the ground or surface of the sea, or even beneath the sea. It may be manned or unmanned, guided or unguided, maneuverable or in a fixed trajectory. It may travel at speeds that range from a few knots to several times the speed of sound.

The term *weapons system* is a generalization encompassing a broad spectrum of components and subsystems. These components range from simple devices operated manually by a single person to complex devices operated by computers.

To accomplish one specific function, a complex array of subsystems may be interconnected by computers and data communication links. This interconnecting allows the array to perform several functions or to engage numerous targets simultaneously. Although each subsystem may be specifically designed to solve a particular part of the fire control problem, having these components operate in concert that allows the whole system to achieve its ultimate goal — the neutralization of the target.

Components

All modern naval weapons systems, regardless of the medium they operate in or the type of weapon they use, consist of the basic components that allow the system to *detect, track* and *engage* the target. Sensor components must be designed for the environments in which the weapon system and the target operate. These components must also be capable of coping with widely varying target characteristics, including target range, bearing, speed, heading, size and aspect.

Detecting the Target

There are three phases involved in target detection by a weapons system. The first phase is surveillance and detection, the purpose of which is to search a predetermined area for a target and detect its presence. This may be accomplished actively, by sending energy out into the medium and waiting for the reflected energy to return, as in radar, or passively, by receiving energy being emitted by the target, as by ESM in our scenario. The second phase is to measure or localize the target's position more accurately and by a series of such measurements estimate its behavior or motion relative to ownship. This is done by repeatedly determining the target's range, bearing, and depth or elevation. Finally, the target must be classified; that is, its behavior must be interpreted to estimate its type, number, size and most importantly, identity. The capabilities of weapon system sensors are measured by the maximum range at which they can reliably detect a target and their ability to distinguish individual targets in a multi-target group. In addition, sensor subsystems must be able to detect targets in a medium cluttered with noise, which is any energy sensed other than that attributed to a target. Such noise or clutter is always present in the environment because of reflections from rain or the earth's surface or because of deliberate radio interference or jamming. It is also generated within the electronic circuitry of the detecting device.

Tracking the Target

Sensing the presence of a target is an essential first step to the solution of the fire control problem. To successfully engage the target and solve the problem, updates of the target's position and velocity relative to the weapon system must be continually estimated. This information is used to both evaluate the threat represented by the target and to predict the target's future position and a weapon intercept point so the weapon can be accurately aimed and controlled. To obtain target trajectory information, methods must be devised to enable the sensor to follow or track the target. This control or "aiming" may be done by a collection of motors and position-sensing devices called a *servo system*. Inherent in the servo process is a concept called *feedback*. In general, feedback provides the system with the difference between where the sensor is pointing and where the target is actually located. This difference is called *system error*. The system takes the error and, through a series of electro-mechanical devices, moves the sensor or weapon launcher in the proper direction and at a rate that reduces the error. The goal of any tracking system is to reduce this error to zero. Realistically this isn't possible, so when the error is minimal the sensor is said to be "on target." Sensor and launcher positions are typically determined by devices that are used to convert mechanical motion to electrical signals. Synchro transformers and optical encoders are commonly used in servo systems to detect the position and to control the movement of power drives and indicating devices. Power drives move the radar antennas, directors, gun mounts, and missile launchers.

The scenario presented in the beginning of this section was in response to a single target. In reality, this is rarely the case. The modern "battlefield" is one in which sensors are detecting numerous contacts, friendly and hostile, and information is continually being gathered on all of them. The extremely high speed, precision, and flexibility of modern computers enable the weapons systems and their operators to compile, coordinate, and evaluate the data, and then initiate an appropriate response. Special-purpose and general-purpose computers enable a weapons system to detect, track, and predict target motion automatically. These establish the target's presence and define how, when, and with what weapon the target will be engaged.

Engaging the Target

Effective engagement and neutralization of the target requires that a destructive mechanism, in this case a warhead, be delivered to the vicinity of the target (see figure 2-15). How close to the target a warhead must be delivered depends on the type of warhead and the type of target. In delivering the warhead, the aiming, launch, type of weapon propulsion system, and the forces to which the weapon is subjected enroute to the target must be considered. The weapon's capability to be guided or controlled after launch dramatically increases its accuracy and probability of kill. The use of guidance systems also dramatically complicates system designs. These factors as well as the explosive to be used, the fuzing mechanism, and warhead design are all factors in the design and effectiveness of a modern weapon.

CRUISE MISSILE SYSTEMS

The U. S. Navy has two surface ship cruise missile systems; Harpoon and Tomahawk. Harpoon is the primary anti-ship cruise missile (ASCM) and Tomahawk is a long-range land attack. Both the Harpoon and Tomahawk systems can be found on cruisers, and destroyers, while the FFG's only have the Harpoon system.

HARPOON MISSILE

A Harpoon missiles (fig. 2-16) is an effective all-weather sea skimming, anti-ship missile with over-the-horizon range.

Missile Features

The features of the Harpoon missile (fig. 2-17) include guidance section, warhead, sustainer section, control section, and booster, which will be discussed in the following paragraphs.

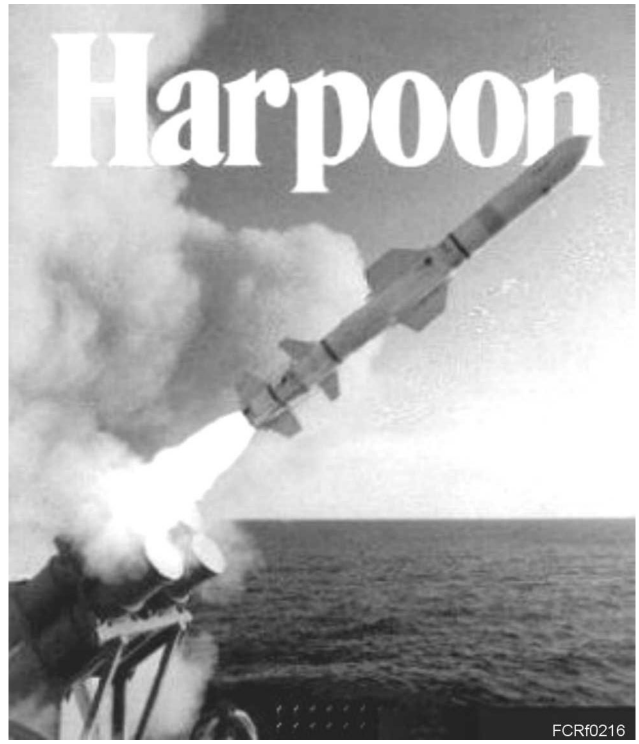

Figure 2-16.—Harpoon missile.

Guidance Section.—The guidance section provides all-weather capability and superior performance in an EW environment. An attitude reference assembly (ARA) plus a digital computer and a radar altimeter are used for midcourse guidance. A frequency-agile seeker is used for terminal guidance. Targeting information includes: radar, sonar, ESM, and other friendly forces (third party), and can be input either automatically or manually before launch. Various missile salvos, waypoints, seeker search patterns, and terminal maneuvers are used for targeting.

Warhead.—The warhead is a 500-pound, blast/fragmentation, high-explosive warhead. A delayed fuze allows warhead penetration prior to detonation into target's hull.

Sustainer Section.—The sustainer section consists of a turbojet engine, a fuel tank with JP-10 fuel, two batteries to power missile through flight, and 4 missile wings.

Control Section.—The control or boat-tail section supports the four control fins and the electromechanical actuators, which steer the missile in flight.

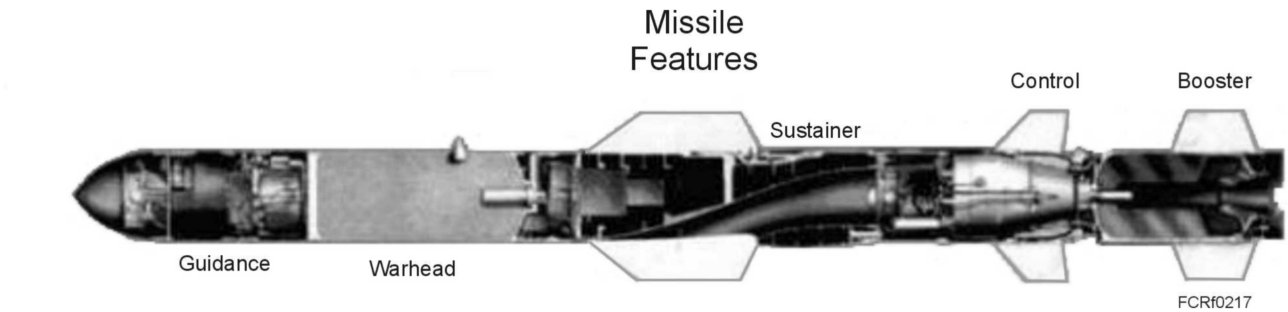

Figure 2-17.—Harpoon missile features.

Booster.—Harpoon employs a solid rocket booster to accelerate the missile to cruise velocity. The booster separates after launch, approximately. 2 kyds down range.

Flight Profile

When a Harpoon is launched, the turbojet engine starts automatically before booster separation. Using the MGU and data from the radar altimeter, the missile flies at the optimum height for the prevailing sea state. This radar seeker is initialized at mid-course cruise altitude as it approaches the target. After acquisition, Harpoon immediately descends to the sea skimming altitude. Just before target impact, the missile executes a shallow pop-up or maintains sea-skimming altitude.

Salvos

There are three different firing salvos used in the Harpoon system; STOT, DTOT and RIPPLE.

- STOT or simultaneous time on top. 2-to 4-missile salvo from one firing platform designated to impact target simultaneously. Designed for one ship to overwhelm target's defenses.
- DTOT or designated time on top. 2 or several missile salvos designated to impact target at designated time (I.E. 1300Z). Designed for using more than one firing platform to overwhelm target's defenses.
- RIPPLE. Platform firing salvos as quickly as system will allow.

Search Patterns

The Harpoon system has two operator selected search patterns, the

- Elliptical (RBL)—used when targets bearing and range are known, and the
- Rectangular (BOL)—used when uncertain range and accurate bearing information of target are available.

TOMAHAWK MISSILE

The Tomahawk Weapon System supports the Navy mission of sea control and projection of power with a long-range, low-altitude attack of land targets with a conventional warhead land strike capability. (See figures 2-18 and 2-19). The TWS provides the capability to attack inland targets in areas where the United States may or may not have sea or air control. The TWS is composed of the following components: All-Up-Round (AUR), Vertical Launch System (VLS), launch platform, Theater Mission Planning Center (TMPC) /Afloat Planning System (APS), and the Advanced Tomahawk Weapon Control System

Figure 2-18.—Tomahawk missile launch.

Figure 2-19.—Tomahawk missile.

(ATWCS). The ATWCS improvements include hardware (including the use of the Navy's standard tactical computers), software, and firmware modifications that introduce new capabilities, such as contingency-strike operations planning, embedded training at all levels, and a simplified man-machine interface which reduce overall reaction time, enhance training capabilities at all levels, reduce operator workload, and improve Tomahawk strike effectiveness. ATWCS incorporates an open architecture to provide for future growth and enhances command and control interoperability.

The missile is an all-weather submarine or ship-launched land-attack cruise missile. After launch, a solid propellant propels the missile until a small turbofan engine takes over for the cruise portion of flight. Tomahawk is a highly survivable weapon. Radar detection is difficult because of the missile's small cross-section, low-altitude flight. Similarly, infrared detection is difficult because the turbofan engine emits little heat. Systems include Global Positioning System (GPS) receiver; an upgrade of the optical Digital Scene Matching Area Correlation (DSMAC) system; Time of Arrival (TOA) control, and improved 402 turbo engines.

The two variants of Tomahawk cruise missile are distinguished by their warhead; TLAM-C has a conventional unitary warhead, and TLAM-D has a conventional sub-munitions (dispense bomblets) warhead. Both are identical in appearance, but different in capabilities. The missile is delivered to ships and submarines as an all-up-round (AUR), which includes the missile that flies the mission, the booster that starts its flight, and the container (canister for ships and capsule for submarines) that protects it during transportation, storage and stowage, and acts as a launch tube.

Tactical Tomahawk will add the capability to reprogram the missile while in-flight to strike any of 15 preprogrammed alternate targets or redirect the missile to any Global Positioning System (GPS) target coordinates. It also would be able to loiter over a target area for some hours, and with its on-board TV camera, would allow the war fighting commanders to assess battle damage of the target, and, if necessary redirect the missile to any other target. Tactical Tomahawk would permit mission planning aboard cruisers, destroyers and attack submarines for quick reaction GPS missions.

SUMMARY

This chapter has given you an overview of many of the fire control systems used in today's Navy. The goal of this chapter was not to tell you every detail of every fire control system, but to simply explain what fire control systems are found on which ships in the Navy and on what types of ships you will find various fire control systems.

One of the key tools used for the "detect-to-engage" scenario is radar systems. Understanding how your ship accomplishes the detect-to-engage scenario is extremely important to every Fire Controlman. Doing so will give you a clear, firm grasp of what your ship does in a battle scenario and how you fit in the big picture of naval warfare for your ship. You should also understand the fire control problem in relationship to this scenario. The detect-to-engage process and fire control problem work together to accomplish the goal of destroying an enemy target. Each ship has its own, unique configuration of weapons and radar systems; it is your responsibility as a Fire Controlman to learn how these work together in the detect-to-engage sequence and the fire control problem.

CHAPTER 3

RADAR SAFETY

LEARNING OBJECTIVES

Upon completing this section, you should be able to:

1. Identify and explain the radiation hazards associated with maintaining and operating radar.
2. Identify the safety precautions associated with maintaining radar equipment.
3. Identify safety devices associated with maintaining radar equipment.
4. Identify other hazards associated with maintaining radar equipment.

INTRODUCTION

Throughout your military career, you will be "bombarded" with safety slogans, rules, and procedures concerning almost every job that you do. There is a reason for this. Your command is trying to keep you alive and well. Your part in this process is to become safety "conscious" to the point that you approach every job from the safety point of view. In this chapter, we will address the specific safety measures and devices associated with operating and maintaining radar equipment.

RADIATION SAFETY

One of the hazards associated with maintaining radar equipment is exposure to RFR (Radio Frequency Radiation). Radar peak power may reach a million watts or more. Therefore, you must remain aware of the RFR hazards that exist near radar transmitting antennas. These hazards are present not only in front of an antenna but also to its sides and sometimes even behind it because of spillover and reflection. Exposure to excessive amounts of radiation can produce bodily injuries ranging from minor to major (Think of how food is cooked in a microwave oven.). The extent of injuries depends on the RFR frequency and the time of exposure. At some frequencies, exposure to excessive levels of radiation will produce a noticeable sensation of pain or discomfort to let you know that you have been injured. At other frequencies, you will have no warning of injury. If you suspect any injury, see your ship's doctor or corpsman. Be sure to acquaint yourself with the actual radiation hazard zones of the radar on your ship.

Whenever you work around radar equipment, observe the following precautions to avoid being exposed to harmful RFR:

- Do not inspect feedhorns, open ends of waveguides or any opening emitting RFR energy visually unless you are sure that the equipment is definitely secured for that purpose.
- Observe all RFR hazard (RADHAZ) warning signs (fig. 3-8). They point out the existence of RFR hazards in a specific location or area.
- Ensure that radiation hazard warning signs are available and used.
- Ensure that radar antennas that normally rotate are rotated continuously or that they are trained to a known safe bearing while they are radiating.

HAZARDS OF ELECTROMAGNETIC RADIATION

Studies have shown that humans cannot easily sense electromagnetic radiation (EMR), also referred to as radio frequency radiation (RFR). Furthermore, EMR at frequencies between 10 kilohertz (kHz) and 300 gigahertz (GHz) presents a hazard to humans and to some materials. Since radiation at these frequencies is common in the Navy's electromagnetic environment, its presence must be detected and announced to ensure the safety of personnel involved in various activities within the electromagnetic environment. A discussion of the various methods used to detect electromagnetic energy is beyond the scope of this NRTC. However, we must emphasize the importance of remaining alert to the danger of overexposure to EMR.

Radiation hazards can be broken down into three categories:

- Hazards of Electromagnetic Radiation to Ordnance (HERO)
- Hazards of Electromagnetic Radiation to Fuel (HERF)
- Hazards of Electromagnetic Radiation to Personnel (HERP)

We will discuss each of these categories in more detail in the following paragraphs.

Hazards of Electromagnetic Radiation to Ordnance (HERO)

The high intensity radio frequency (RFR) fields produced by modern radio and radar transmitting equipment can cause sensitive electroexplosive devices (EEDs) contained in ordnance systems to actuate prematurely. The Hazards of Electromagnetic Radiation to Ordnance (HERO) problem was first recognized in 1958. The prime factors causing the problem have been increasing ever since. The use of EEDs in ordnance systems has become essential. At the same time, the power output and frequency ranges of radio and radar transmitting equipment have also increased.

RFR energy may enter an ordnance item through a hole or crack in its skin or through firing leads, wires, and so on. In general, ordnance systems that are susceptible to RFR energy are most susceptible during assembly, disassembly, loading, unloading, and handling in RFR electromagnetic fields.

The most likely results of premature actuation are propellant ignition or reduction of reliability by dudding. Where out-of-line Safety and Arming (S + A) devices are used; the actuation of EEDs may be undetectable unless the item is disassembled. If the item does not contain an S + A device, or if RFR energy bypasses the S + A device, the warhead may detonate.

Ordnance items susceptible to RFR can be assigned one of three HERO classifications, based upon the probability that they will be adversely affected by the RFR environment. Those classifications are:

1. HERO Safe. An ordnance item sufficiently shielded or protected to make it immune to adverse effects from RFR when used in its expected shipboard RFR environments.
2. HERO susceptible. Ordnance containing EEDs proven by tests to be adversely affected by RFR energy to the point that safety or reliability may be in jeopardy when the ordnance is used in RFR environments.
3. HERO unsafe. Any electrically initiated ordnance item that becomes unsafe when:
   a. Its internal wiring is physically exposed.
   b. Tests being conducted on the item require additional electrical connections to be made.
   c. Electroexplosive devices (EEDs) having exposed wire leads are present, handled, or loaded.
   d. The item is being assembled or disassembled.
   e. The item is in a disassembled condition.
   f. The item contains one or more EEDs and has not been classified as HERO safe or susceptible by either a test or design analysis.

To ensure the HERO safety and HERO reliability of ordnance systems, the Naval Sea Systems Command sponsors an extensive testing program to determine their susceptibility to RFR energy. HERO requirements and precautions are provided in NAVSEA OP 3565/NAVAIR 16-1-529/NAVELEX 0967-LP-624-6010/Volume II, *Electromagnetic Radiation Hazards (U) (Hazards to Ordnance) (U)*. You will find your ship's specific requirements in its HERO Emission Control (EMCON) bill.

The commanding officer of each ship or shore station is responsible for implementing HERO requirements. He or she must also establish a procedure to control radiation from radio and radar antennas among personnel handling ordnance and personnel controlling radio and radar transmitters. The commanding officer does this through a command instruction based on the ship's mission and special features. This instruction is usually part of the Ship's Organization Manual and is the basis for department and division instructions.

Hazards of Electromagnetic Radiation to Fuels (HERF)

Many studies have been done about fuel vapors being accidentally ignited by electromagnetic radiation. Tests aboard ships and in laboratories have shown that the chances of this happening are low because of other conditions that must exist at the same time to support combustion of the fuel. Although accidental ignition of fuel by RFR is unlikely, you still need to be aware of the potential hazards. The most likely time this might occur is during a ship's refueling evolutions, commonly called UNREPs (Underway Replenishment). Many ships also carry at least one helicopter or have the ability to refuel a helicopter and, therefore, carry fuel to support helo operations. All of these operations are inherently dangerous by themselves and require the utmost attention and alertness. As a junior Fire Controlman you most likely will be personally involved in these refueling operations. You need to be aware of the potential hazards associated with fire-control radar and fuel. As a senior Fire Controlman, you need to know the hazards of electromagnetic radiation to fuel, so you can ensure that your division personnel are working in a safe environment.

RADAR RESTRICTIONS.—*Electromagnetic Radiation Hazards (U) (Hazards to Personnel, Fuel and Other Flammable Material) (U),* NAVSEA OP 3565/NAVAIR16-1-529/NAVELEX 0967-LP-624-6010/Volume I specifies the safe distances from radiating sources at which fueling operations may be conducted. Figure 3-1 indicates safe distances between fueling operations and a conical monopole antenna, based on transmitter power. Each type of antenna has its own chart. Refer to your ship's Emissions Control (EMCON) bill for specific guidance concerning fueling operations.

FUEL RESTRICTIONS.—As the RFR energy radiated from high-powered communications and radar equipment installed on ships increased in recent years, the Navy shifted to less volatile fuels. Under normal operating conditions, volatile mixtures are present only near aircraft fuel vents, open fuel inlets during over-the-wing fueling, and near fuel spills.

Before fuel vapors can ignite, three conditions must exist simultaneously:

1. For a given ambient temperature, the mixture must contain a specific ratio of fuel vapor to air.
2. There must be enough energy in the arc or spark to produce the appropriate temperature for ignition.
3. The length of the arc must be sufficient to sustain the heat in the arc for the time required to initiate a flame.

Each of these conditions is likely to vary for every situation, and two of the conditions may exist at any given time. Although all three conditions will probably not occur simultaneously, the consequences of an accidental explosion make it very important to be careful.

Hazards of Electromagnetic Radiation to Personnel (HERP)

The RFR hazard category of most immediate concern to you is HERP. The heat produced by RFR may adversely affect live tissue. If the affected tissue cannot dissipate this heat energy as fast as it is produced, the internal temperature of the body will rise. This may result in damage to the tissue and, if the temperature rise is sufficiently high, in death.

The Bureau of Medicine and Surgery has established safe exposure limits for personnel who must work in an electromagnetic field based on the power density of the radiation beam and the time of exposure in the radiation field. Before we discuss these further, we must discuss some additional terms.

Specific Absorption Rate (SAR)—This is the rate at which the body absorbs non-ionizing RFR. The threshold at which adverse biological effects begin is 4 watts per kilogram of body mass (W/kg). With a safety factor of 10 added, the accepted threshold is 0.4 W/kg for the whole body, averaged over any 6-minute (0.1 hour) period. A special limit for "hot spot" or limited body exposure has been set at 8.0 W/kg, averaged over any 1 gram of body tissue for any 6-minute period. Although this rate of absorption is very important in determining whether or not a safety hazard exists, it is very difficult to measure. Measuring this rate of absorption can also be dangerous since it requires actual exposure of body tissue. A related measure that gives an acceptable indication of SAR is "Permissible Exposure Limit."

Permissible Exposure Limit (PEL)—This is a limit to RFR exposure based on measurements of radiation's electric field strength (E) or magnetic field strength (H) taken with instruments. You can use available charts to determine whether the

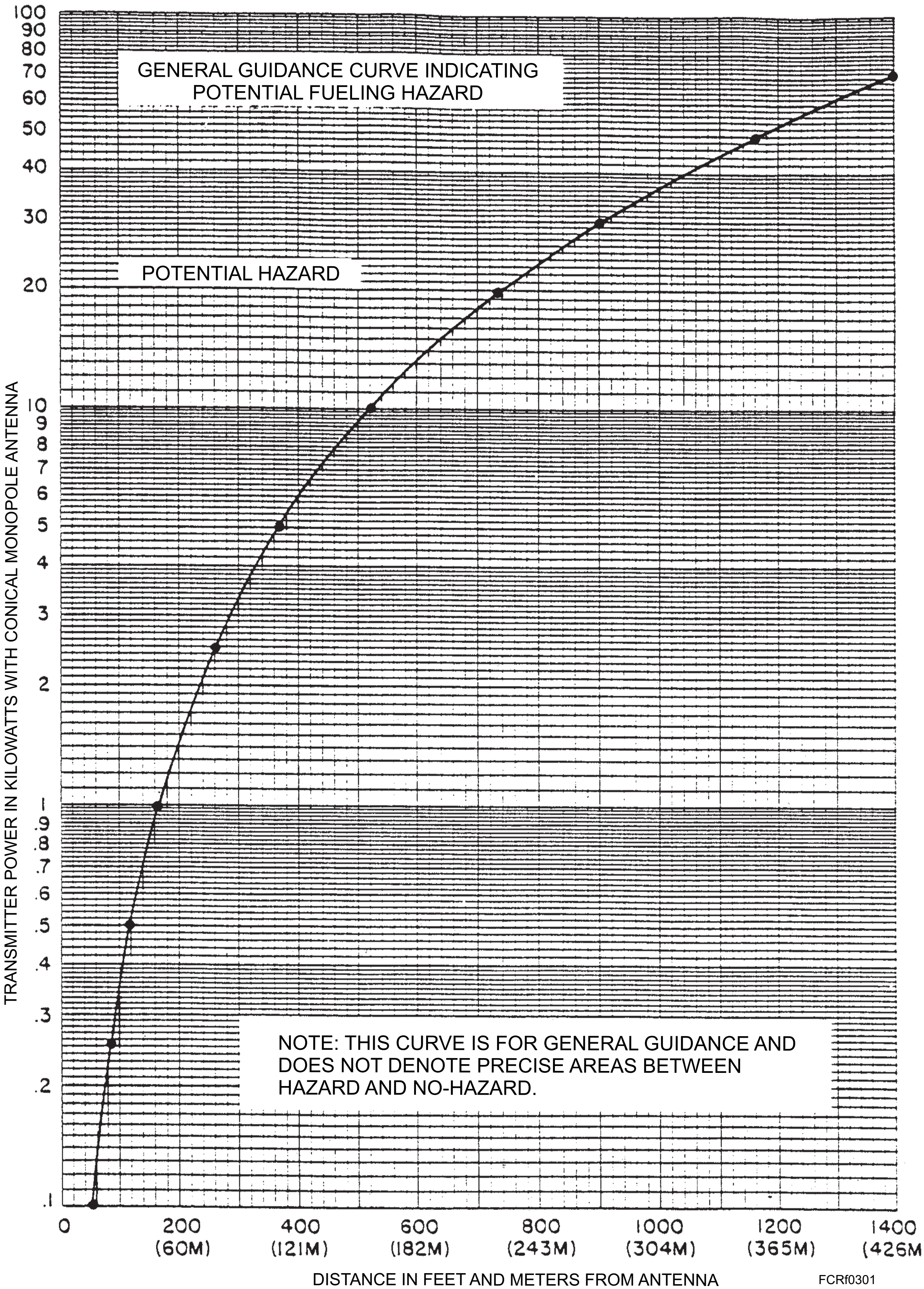

Figure 3-1.—Guidance Curve for Potential Fueling Hazards.

strength of the field presents a biological hazard to personnel located at the point where the measurements were taken. PEL readings are the basis for determining RADHAZ safety boundaries.

Permissible Exposure Time (PET)—This is the maximum time of exposure to a specific power density for which the PEL will not be exceeded when the exposure is averaged over any 6-minute period. Table 3-1 shows the PET for a variety of radars operated at their normal power levels.

If you suspect that you or someone else has been overexposed to EMR, follow the flow chart in figure 3-2. If you confirm your suspicions, the exposure is considered an incident and must be reported as required by *Protection of DOD Personnel from Exposure to Radio Frequency Radiation*, DOD Instruction 6055.11.

RFR HAZARDS TO THE SKIN.—The energy impinging on a person in an electromagnetic field may be scattered, transmitted, or absorbed. The energy absorbed into the body depends upon the dimensions of the body, the electrical properties of the tissues, and the wavelength of the RFR. Thus, the wavelength of the energy and its relationship to a person's dimensions are important factors bearing on the biological effects produced by RFR.

Significant energy absorption will occur only when a personal dimension is equivalent to at least one-tenth of a wavelength. As the frequency of radiation increases, the wavelength decreases and the person's height represents an increasingly greater number of electrical wavelengths, increasing the danger from RFR exposure. As the frequency is decreased, the wavelength increases and the person becomes a less significant object in the radiation field. Thus, the likelihood of biological damage increases with an increase in radiation frequency. Also, as the radiation frequency increases and the wavelength becomes progressively shorter, the dimensions of parts and appendages of the body become increasingly significant in terms of the number of equivalent electrical wavelengths.

When a person stands erect in a RFR field, the body is comparable to a broadband receiving antenna. When any of the major body dimensions are parallel to the RFR energy's plane of polarization, the produced effects are likely to be more pronounced than when they are oriented in other positions.

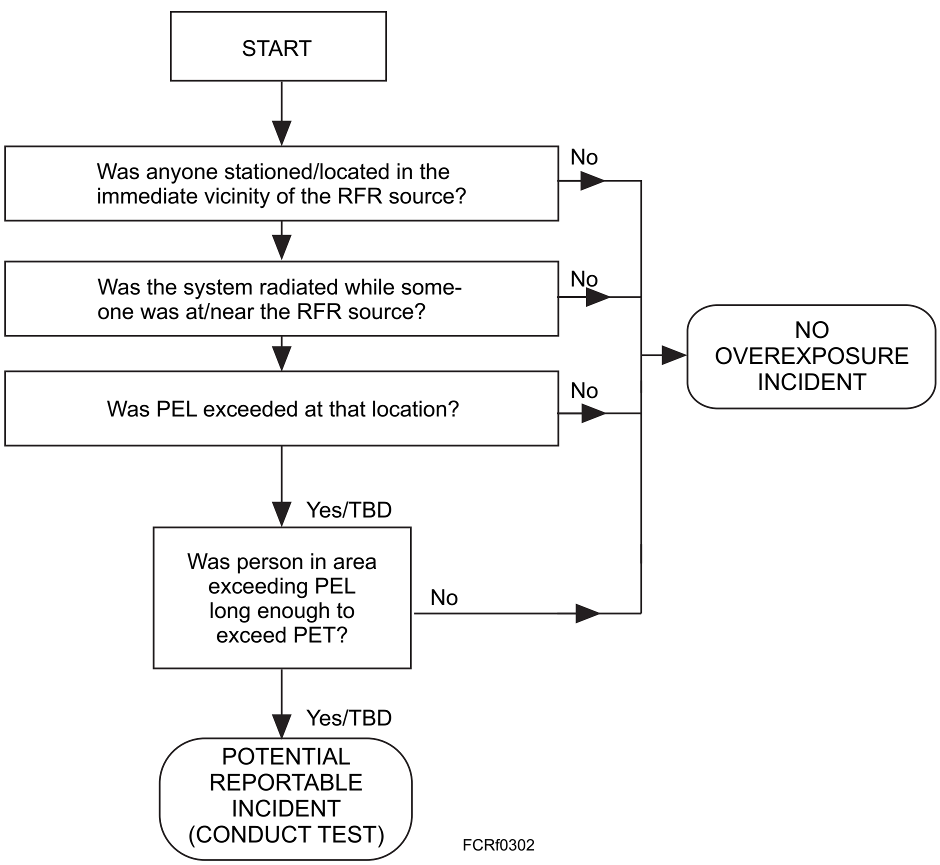

Figure 3-2.—Personnel RFR exposure decision chart.

Table 3-1.—Permissible Exposure Time Limits—Partial List

XMITTER	MODE	FIXED BEAM HAZARD			MOVING BEAM		
		DISTANCE		MAX EXP TIME	PERSONNEL HAZARD	DISTANCE	
		METERS	FEET			METERS	FEET
AN/APX-72	ALL	1	3	6	N/A	-	-
AN/APX-72A		1	3	6	N/A	-	-
AN/SPS-29, B, C, E		24	80	0.3	YES	5	17
AN/SPS-37		46	150	0.08	YES	11	35
AN/SPS-37A		76	250	0.5	YES	6	19
AN/SPS-40, A, B		29	95	0.5	YES	1.5	5
AN/SPS-43		46	150	0.2	YES	10	33
AN/SPS-43A		79	260	0.3	YES	5	17
AN/SPS-48E	BURNTHRU	427	1400	0.09	YES	6	19
AN/SPS-49		61	200	1.53	NO	-	-
AN/SPS-52, A, B, C		131	430	0.74	NO	-	-
AN/SPS-53, A, D, E, J, K, L		1	3	6	NO	-	-
AN/SPS-58, A, C		1	3	6	NO	-	-
AN/SPS-60		1	3	6	NO	-	-
AN/SPS-62		1	3	6	NO	-	-
AN/SPS-64		1	3	6	NO	-	-
AN/SPS-66		1	3	6	NO	-	-
AN/SPY-1		427	1400	0.23	NO	-	-
AN/SRQ-4		1	3	6	NO	-	-
AN/TPN-30	AZ/EL	18	60	3.2	NO	-	-
AN/TPX-42A(V)8		1	3	6	N/A	-	-
AN/ULQ-6A, B, C		5	15	2.2	N/A	-	-
AN/UPX-12B		1	3	6	N/A	-	-
AN/UPX-17		1	3	6	N/A	-	-
AN/UPX-23		1	3	6	N/A	-	-
AN/UPX-25(V)4		1	3	6	N/A	-	-
AN/UPX-27		1	3	6	N/A	-	-
AN/URN-20, B, C, D(V)1		1	3	6	N/A	-	-

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The depth of penetration and coincident heating effects of energy on the human body depend on the energy's frequency. The region of transition between major damage and minor or no damage is between 1 and 3 GHz. Below 1 GHz, the RFR energy penetrates to the deep body tissues. Above 3 GHz, the heating effect occurs closer to the surface. At the higher frequencies, the body has an inherent warning system in the sensory elements located in the skin. At frequencies between 1 and 3 GHz, the thermal effects are subject to varying degrees of penetration, with the percentage of absorbed energy ranging from 20 to 100 percent. The two microwave cooking oven frequencies fall close to this range. The lower frequency, 915 MHz, produces a deeper heating effect on tissue (i.e., roasts) and is not as effective for surface cooking (browning) as the higher frequency, 2,450 MHz.

RFR HAZARD TO THE EYES.—The transparent lens of the eye may be damaged by radiated energy (ultraviolet, infrared, or radio frequency), causing the development of cataracts or opacities. The lens is very susceptible to thermal damage, since it has an inefficient vascular system to circulate blood and exchange heat to the surrounding tissues. Unlike other cells of the body, the cells of the lens cannot be replaced by regrowth. When cells in the lens die or become damaged, a cataract may form. The damaged cells may lose their transparency slowly and, depending upon the extent of damage, cause the individual to suffer impaired vision. Apparently, the presence of even a relatively few damaged cells may act upon other lens cells, either by releasing toxic substances or by preventing normal chemical transformation to take place within other cells.

RFR HAZARD TO THE TESTICLES.—Testicular reaction to heat injury from excessive exposure to RFR radiation can be the same as the reaction to a high fever associated with many illnesses. Although a condition of temporary sterility may occur, the condition does not appear to be permanent and will ultimately correct itself. However, injury to the testicles may be permanent because of an extremely high dosage or because of high exposures for extended periods of time (i.e., months to years).

SHIPBOARD RADIATION HAZARD ZONES.—Because of the danger of radiation hazards to personnel, the fire control radar is equipped with cutout switches that turn off the transmitter for certain director bearings and elevations. The information concerning cutout zones for your particular installation is located in the radar OPs(Operational Publications). You should know the cutout zones for your particular radar. The equipment OPs also give the radiation pattern and the minimum safe distance for personnel exposed to the mainbeam of the radar. The safe limit of radiation exposure to personnel, established by the Naval Medical Command, is 10 mW/cm averaged over any one-tenth hour period (six minutes). No exposure in a field with a power density in excess of 100 mW/cm is permitted.

RFR Burns

You can receive an RFR burn if your skin contacts a source of RFR voltage. This is because your skin's resistance to the current flow in the area of contact produces heat. The effect of this heat on your skin can range from noticeable warmth to a painful burn.

Mild RFR burns are usually indicated by small white spots on the skin and possibly the odor of scorched skin. More severe burns may penetrate deeper into the flesh and produce painful and slower healing injuries. For our purposes, "hazardous" will be associated with the RFR voltage level sufficient to cause pain, visible skin damage, or an involuntary reaction. The term *hazard* does not include the lower voltage that causes annoyance, a stinging sensation, or mild heating of the skin. **The Naval Ships Engineering Center has prescribed that an open circuit RFR voltage exceeding 140 volts on an object in an RFR radiation field be considered hazardous.**

A common source of potential RFR burns is crane hooks. Transmitting antennas can induce RFR voltages in nearby crane structures and wire ropes. Figure 3-3 shows areas on a crane in which inductive and capacitive charges may be induced by RFR. Some crane/antenna problems can be eliminated by relocating the associated antennas, but each installation requires special considerations. The locations of ship's antennas are based on the desired radiation patterns, taking into account the physical limitations imposed by the ship's structure. Often, the relocation of antennas, although physically permissible, is not feasible because of the location of the associated transmitters.

RFR voltages measured aboard ships show that resonance effects may occur at frequencies between 2 and 30 Mhz. The careful use of frequency can reduce the coupling of RFR voltages induced in crane structures and rigging. A better approach, however, is the use of RFR high voltage insulator links, which

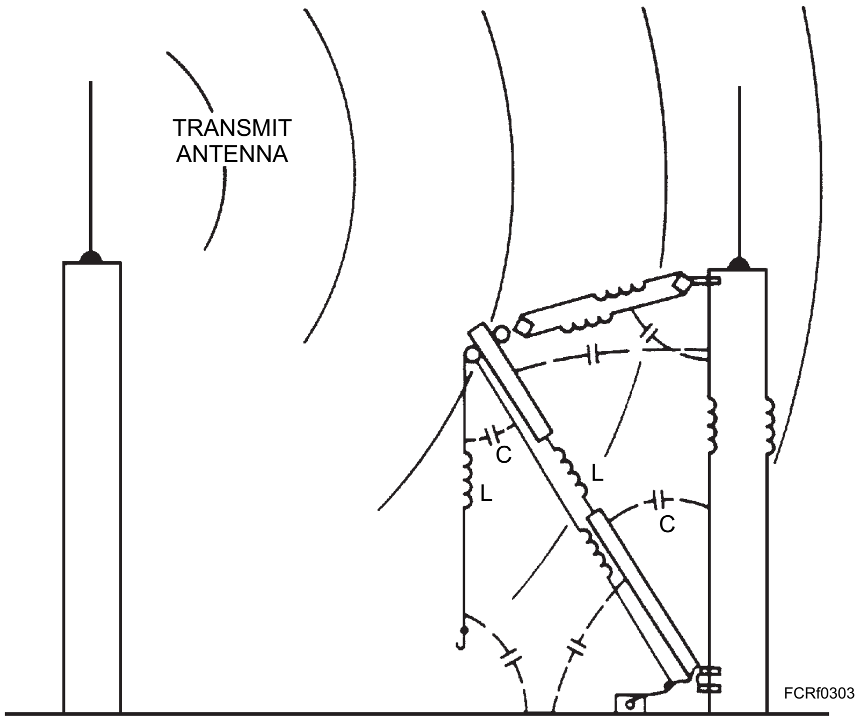

Figure 3-3.—Electrical equivalent of cargo handling equipment.

provide protection for personnel against RFR burns. (Refer to *Link RFR High Voltage Insulator for Ship Cranes*, MIL-L-24410 (SHIPS)). Two separate bands of fiberglass filament wound on two zinc-coated steel saddles provide the required high electrical resistance, low capacitance, high tensile strength, ruggedness and fail-safe features of the insulator links. While the inner band normally carries the full working load, the outer band can carry the full working load if the inner band breaks.

When proper precautions are taken, personnel handling rigging will not be harmed as long as nearby electronic transmitting equipment is operated at an output of 250 watts or less, average (at any frequency). HOWEVER, PERSONNEL SHOULD BE CONSTANTLY ALERT TO THE FACT THAT EVEN UNDER THE ABOVE OPERATIONAL LIMITS, ELECTRONIC TRANSMITTING EQUIPMENT CAN CAUSE HAZARDOUS VOLTAGES TO BE INDUCED IN THE STANDING RIGGING AND OTHER PORTIONS OF A SHIP'S STRUCTURE, PARTICULARLY STRUCTURES AND OBJECTS (i.e., AIRPLANES AND HELICOPTERS) THAT PROTRUDE FROM THE SHIP IN THE SAME PLANE AS THE RADIATING SOURCE. The RFR voltage induced in a ship's structures, rigging, or other objects will cause burns to personnel when they contact conductive objects. The burn hazard problem, its causes, and remedial techniques are discussed in chapter 3 ("RFR Burns") of *Electromagnetic Radiation Hazards (U) (Hazards to Personnel, Fuel and Other Flammable Material) (U),* NAVSEA OP 3565/NAVAIR 16-1-529/ NAVELEX 0967-LP-624- 6010/Volume I.

MAN ALOFT SAFETY

Since many areas on the exterior of a ship that contain radar equipment are inaccessible from decks or built-in work platforms, someone must go aloft to work in these areas. We define "aloft" as any mast, kingpost, or other structure where the potential for a fall exists. Probably the greatest hazard associated with working aloft is the danger of a fall. Other hazards include electrical shock, radiation burns, asphyxiation from stack gasses, and the dropping of objects.

As long as nearby equipment is turned off, you should not have to worry about receiving a shock from current generated by the equipment. However, you must be aware of the possibility of shock due to static charges. Static charges are caused by electrically charged particles that exist naturally in the water. Under certain conditions these charged particles collect on metallic objects such as wire antennas and produce a shock hazard. You can eliminate this hazard by grounding these objects. Shocks from static charges will not harm you directly, but the surprise of such a shock may cause you to fall.

WORKING ALOFT CHECK SHEET

Because of the associated dangers, no one may go aloft on masts, stacks, or kingposts without first obtaining permission from the Officer of the Deck (OOD), as prescribed by the *Navy Occupational Safety and Health (NAVOSH) Program Manual for Forces Afloat*, OPNAVINST 5100.19 series. Before granting permission, the OOD must ensure that the Working Aloft Check Sheet (fig. 3-4) has been properly completed and routed. When the ship is underway, the commanding officer's permission is required to work

WORKING ALOFT CHECK SHEET

USS ____________________ Time/Date ____________

1. Personnel will be going aloft at (location) ____________ for accomplishing the following work ____________
____

2. Prior to allowing personnel to go aloft, accomplish the following:

Initials

_____ a. If underway, obtain the commanding officer's permission.

_____ b. DANGER tag-out all rotating equipment, such as radar antennas, in the vicinity of the work area.

_____ c. Place a sign on all HF, MF, and LF transmitters and all radars whose danger zone encompasses the work area. The sign should read:

SECURED. PERSONNEL ALOFT
DATE ____________ TIME ____________ INITIALS ____________

_____ d. Ensure personnel going aloft are wearing a parachute type safety harness with a Dyna-Brake® safety lanyard, working lanyard, and climber safety device (if a climber safety tail is installed). Ensure that PMS has been accomplished on all equipment prior to use.

_____ e. Notify the engineering officer of the watch/engineering duty officer to ensure that safety valves are lifted only in an emergncy when personnel are aloft (main control should notify the officer of the deck of an impending emergency as soon as possible to permit warning of personnel aloft).

_____ f. If work is to be accomplished on or in the vicinity of the whistle, secure power to the whistle (steam, air, electricity) and DANGER tag-out.

_____ g. Ensure that personnel are briefed on safety prior to going aloft. This should include, as a minimum, keeping the lanyard attached with a minimum of slack to a fixed structure at all times; changing the lanyard connection point as work progresses; keeping good footing and grasp at all times.

_____ h. Ensure all tools are attached to personnel with preventer lines; or, if passed up, have lanyards attached which are firmly secured before removal from the bucket.

_____ i. Ensure that assistance is provided to keep areas below the working area clear and for passing tools or performing rigging.

_____ j. Ensure that personnel working in the vicinity of stacks, or other areas where they may be subject to exhaust fumes, are wearing proper respiratory protection equipment.

_____ k. Do not permit work aloft, except in an emergency, if wind speed is greater than 30 knots, roll is in excess of 10°, pitch is in excess of 6°, or if ice or thunder storms threaten.

_____ l. If in port, notify officers of the deck/command duty officers of adjacent ship(s) to ensure that high-powered radio and radar transmitters will not be energized and endanger personnel going aloft.

_____ m. Fly the KILO or KILO THREE flag, as appropriate, if in port.

_____ n. Prior to personnel going aloft, have the following passed over the 1MC: "DO NOT ROTATE OR RADIATE ANY ELECTRICAL OR ELECTRONIC EQUIPMENT WHILE PERSONNEL ARE WORKING ALOFT".

_____ o. If a crane is used to suspend personnel, ensure that the crane has a current certification and the work platform is approved by NAVSEA for handling personnel.

3. Conditions have been established to permit personnel working aloft.

____
Command Duty Officer/Officer of the Deck/Time

Working Aloft Commenced ____________
Working Aloft Completed ____________

Note: Initials certify completion of an item. If an item is not applicable, indicate "NA" on initial line.

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Figure 3-4.—Sample Working Aloft Check Sheet.

aloft. The OOD will ensure that appropriate signal flags are hoisted. (KILO for personnel working aloft; KILO THREE for personnel working aloft and over the side.) Before the work begins and every 15 minutes thereafter, he will have the word passed over the 1 MC, "DO NOT ROTATE OR RADIATE ANY ELECTRICAL OR ELECTRONIC EQUIPMENT WHILE PERSONNEL ARE WORKING ALOFT." Additionally the OOD will inform the ships in the vicinity that personnel will be working aloft to ensure that they take appropriate action on the operation of their electrical and electronic equipment. Departments concerned must ensure that all radio transmitters and radars that pose radiation hazards are placed in the STANDBY condition and that a sign reading "SECURED. PERSONNEL ALOFT. DATE _______ TIME _______ INITIALS ________ " is placed on the equipment.

You should always check your ship's instruction (Man Aloft Bill) for specific guidance before you go aloft. Here are some general guidelines to follow when you go aloft:

1. Use a climber sleeve assembly in conjunction with the safety harness where a climber safety rail is installed.
2. Attach safety lanyards to all tools, if practical. Never carry tools up and down ladders. Rig a line and raise or lower your tools in a safe container.
3. Stop work when the ship begins to roll in excess of 10 degrees, or to pitch in excess of 6 degrees, when wind speed is greater than 30 knots, and when an ice storm or lightning threatens.
4. Be sure the petty officer-in-charge has marked off an area below the zone of work and keeps all unnecessary personnel clear. If the slightest chance of danger exists, have personnel in the area moved to safety.
5. Read all safety placards posted in the area before you begin the work.
6. Wear personal protective equipment, such as hearing protection, goggles, gloves, or a respirator for hazards other than RFR.
7. When you perform hot work, replace the personal safety and staging or boatswain chair fiber lines with wire rope. Personal safety lines must consist of CRESS wire rope.

Most ships in today's Navy are aviation capable. Any loose materials or tools that you leave in an outside work area may become foreign object damage (FOD) material. FOD material can be sucked into aircraft engines (causing extensive damage) or blown around by engine exhaust or rotor wash (possibly injuring someone). You must learn the importance of foreign object damage (FOD) control. Supervisory personnel are responsible for ensuring that assigned personnel who work on the mast and other topside areas receive training on the importance of FOD control. After completing any work topside, you must ensure that all tools and materials are removed from the work area. Metallic items left in these areas may also create electromagnetic interference problems.

SAFETY HARNESS

For your own safety, you should wear an approved parachute-type safety harness (fig. 3-5) with a safety lanyard and a tending line (as required) with double locking snap hooks whenever you work aloft. (The lineman-type safety belt is no longer authorized for use.) Safety harnesses should be checked periodically as prescribed by the Planned Maintenance System. Place the tools that you will use on the job in a canvas bag and haul the bag up with a line to the job location. To guard against dropping tools and seriously injuring someone, tie the tool you are using to your safety harness with a piece of line.

The safety harness assembly consists of the following components:

1. Safety harness with lanyards
2. Working lanyard nylon
3. Safety lanyard with Dyna-Brake®
4. Safety harness
5. Safety climbing sleeve

WARNING SIGNS

Warning signs and suitable guards should be posted conspicuously in the appropriate places for the following purposes:

- To keep personnel from accidentally coming into contact with dangerous voltages;
- To warn personnel about possible explosive vapors and RFR radiation;
- To warn personnel working aloft about the poisonous effects of stack gases;

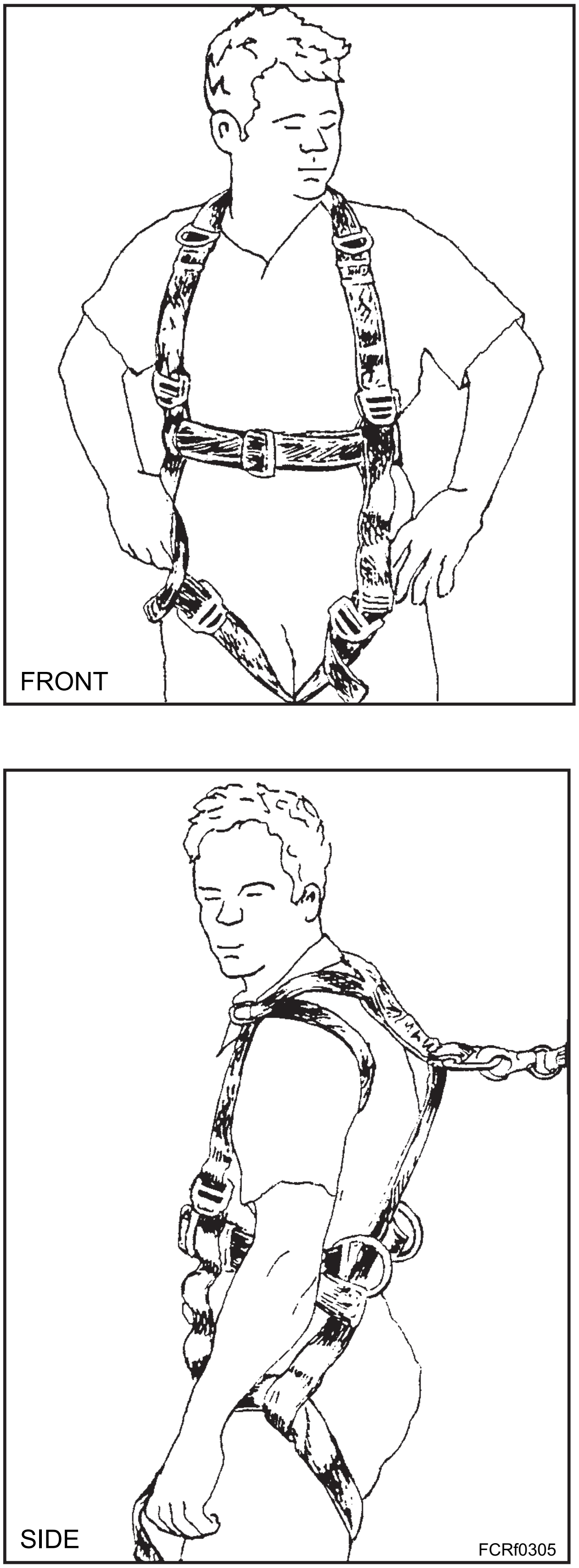

Figure 3-5.—Parachute-type safety harness.

- To warn of other dangers that may cause injuries to personnel.

Installation of equipment is not considered complete unless appropriate warning signs are posted conspicuously.

HIGH VOLTAGE WARNING SIGN

High voltage and shock hazard warning signs should be installed on or in the vicinity of equipment or accessories having exposed conductors at potentials of 30 volts (root mean square or dc) or above. Exposed conductors include those from which personnel may receive a shock by physical contact or by voltage arc over. The signs should be posted so that they are obvious and can be clearly read by personnel entering the area.

Compartments or walk-in enclosures containing equipment with exposed conductors presenting shock hazards in excess of 500 volts (root mean square or dc) should have a “Danger High Voltage” sign (fig. 3-6) posted conspicuously within each entrance.

Compartments or walk-in enclosures containing equipment with exposed conductors presenting shock hazards between 30 volts (RMS or dc) and 500 volts (RMS or dc) should have either a “Danger High Voltage” sign or a “Danger Shock Hazard” sign posted conspicuously within each entrance.

STACK GAS WARNING SIGN

A warning sign to alert personnel working aloft near smoke pipe (stack) gases is shown in figure 3-7. One sign should be mounted near the bottom of each access ladder leading aloft. Another sign should be located at the top of each ladder but mounted on the base of the antenna pedestal.

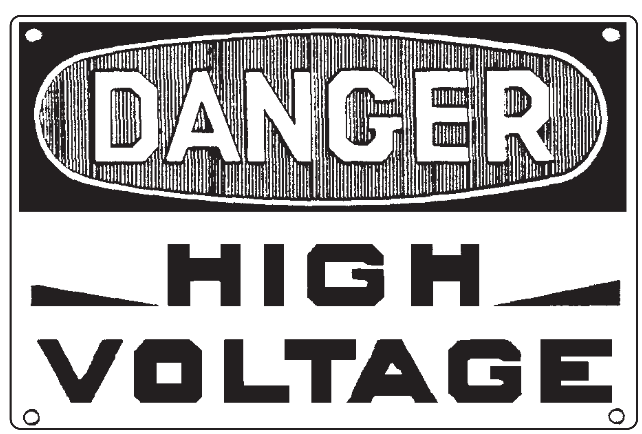

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Figure 3-6.—High voltage warning sign.

FCRf0307

Figure 3-7.—Stack gas warning sign.

RFR HAZARD WARNING SIGNS

There are six RFR radiation hazard (RADHAZ) warning signs (fig.3-8). Requisitioning information is provided on the signs themselves. Consult with your leading petty officer (LPO) to obtain the appropriate signs if they are not posted in your workspace.

RADHAZ signs are made of anodized aluminum and come in two authorized sizes: large (14-inches by 14-inches) and small (5-inches by 5-inches). The large signs are reserved for shore use. The small signs may be used either aboard ship or ashore.

The signs shown in figure 3-8 were approved for use in 1990. Some old style signs may still be posted in various work areas. If you find older style RADHAZ signs posted in an area, you do not have to replace them with the new style signs unless they are damaged or illegible.

The purpose of each type of RADHAZ sign is explained in the following paragarphs.

Type 1—"WARNING RADIO FREQUENCY HAZARD . . . KEEP MOVING"

The type 1 sign advises personnel not to linger in an area surrounding HF antennas where RFR permissible exposure limit (PEL) can be exceeded. There is no danger from exposure to HF radiation in these areas for short periods. However, no one should remain within the area (defined by a 4-inch red line/circle on the deck) longer than 3 minutes within a 6 minute period.

When type 1 signs are required, install them at eye level, or where they can be seen easily, outside the PEL boundary.

Type 2—"WARNING RADIO FREQUENCY HAZARD . . . BEYOND THIS POINT"

The type 2 sign is used to keep personnel from proceeding past a designated point unless they comply with established RADHAZ avoidance procedures. These procedures are discussed in ship's doctrine, such as the "MAN ALOFT BILL." You will probably not find deck markings in these areas.

Type 2 signs are installed at eye level at the bottom of vertical ladders or suspended at waist level between the handrails of inclined ladders. When type 2 signs are used as temporary barriers, such as when weapons direction radars are radiating, they are installed at waist level on a nonmetallic line.

Type 3—"WARNING RADIO FREQUENCY HAZARD . . . BURN HAZARD"

The type 3 sign advises personnel to use special handling procedures when they touch a designated metallic object, or simply to not touch it. This object is an RFR burn source when it is illuminated by energy from a nearby transmitting antenna. Although the hazard may exist only at certain frequencies or power levels, personnel should regard the object as a hazard unless the transmitter is secured.

NOTE: Whenever possible, the RFR burn source should be replaced with a nonmetallic substitute or relocated or reoriented to eliminate the hazard before resorting to a type 3 sign for personnel protection.

A type 3 sign should be installed on the RFR burn source or in the immediate vicinity where it can be seen easily. When used on cargo handling running rigging, type 3 signs should be mounted on the hook insulator. Personnel should be warned to not touch the wire/rigging above the insulator. More than one type 3 sign should be installed on larger burn sources that can be approached from multiple directions.

Type 4—"WARNING RADIO FREQUENCY HAZARD . . . FUELING OPERATIONS"

The type 4 sign advises of the hazards of electromagnetic radiation to fuels (HERF). These signs are normally used only on ships that carry aviation gasoline (AVGAS) or automotive gasoline (MOGAS). Marine diesel fuel and JP-5 jet fuel are not

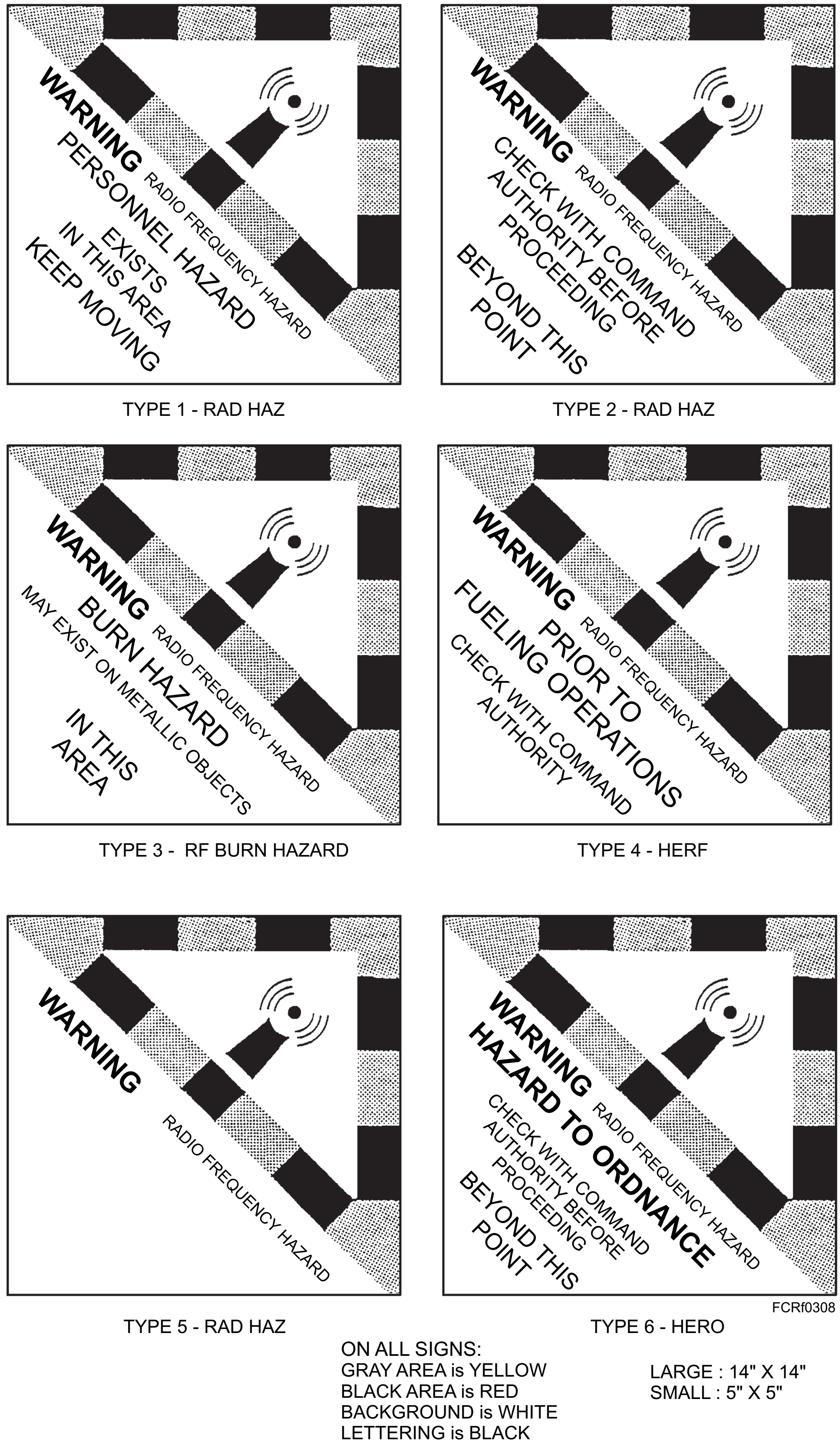

Figure 3-8.—Sample RADHAZ signs.

considered to have a HERF problem and require no special electromagnetic safety precautions during fueling. Most naval ships do not carry gasoline. An exception to this is amphibious ships carrying gasoline-powered landing vehicles. Aboard ships that carry AVGAS or MOGAS, personnel should observe the following precautions during fueling or fuel transfer operations:

1. Secure all transmitting antennas located within the quadrant of the ship in which fueling is being conducted.
2. Ensure that RADHAZ cutouts for microwave radiators are not overridden during fueling, which could result in the illumination of the fueling areas.
3. Do not energize any radar or communications transmitter on any aircraft or vehicle.
4. Do not make or break any electrical, static ground wire, or tie down connection, or any metallic connection to the aircraft or motor vehicle while it is being fueled. Make the connections before the fueling commences. Break them afterward.

Type 5—"WARNING RADIO FREQUENCY HAZARD (SPECIAL CONDITION)"

The type 5 sign has a blank area for filling in special safety precautions. Its purpose is to advise personnel of procedures to follow when other RADHAZ warning signs are not appropriate. Examples of directions that can be filled in on a type 5 sign include:

- "Inform OOD before placing system in radiate."
- "In manual mode, do not depress below horizon between ______ and _______ degrees relative."
- "Ensure temporary exclusion barriers are in place before radiating."
- "Do not stop antenna between _______ and _______ degrees while radiating."

A type 5 sign is normally installed below decks in a system operating room. It should be installed in the vicinity of controls such as a radiate switch or antenna control switch, where the person operating the gear in normal operation can see it. When mounted on system cabinets or control panels, RADHAZ signs should not obscure switch labels, meters, indicators or nameplate data.

Type 6—"WARNING RADIO FREQUENCY HAZARD . . . HAZARD TO ORDNANCE"

The type 6 sign advises of hazards of electromagnetic radiation to ordnance (HERO). NAVSEA OP 3565 explains the purpose of HERO signs and where to place them.

ROTATION HAZARD WARNING

Rotating directors present a serious danger to personnel near them. To guard against this hazard, be sure the topside area near the directors is cleared of all personnel before you energize a director. "DANGER ROTATION HAZARD" warnings should also be posted or painted in conspicuous places to alert unwary personnel.

OTHER RADAR HAZARDS

The hazards we discussed above occur primarily on the exterior of the ship. We now need to discuss some of the radar hazards you may encounter inside the ship.

CATHODE-RAY TUBES (CRTs)

Cathode-ray tubes can be very dangerous and should always be handled with extreme caution. The glass envelope encloses a high vacuum, and because of its large surface area, is subject to considerable force by atmospheric pressure. (The total force on the surface of a 10-inch CRT is 3,750 pounds or nearly 2 tons; over 1,000 pounds is exerted on its face alone.) Proper handling and disposal instructions for a CRT are as follows:

- Avoid scratching or striking the surface.
- Do not use excessive force when you remove or replace the CRT in its deflection yoke or its socket.
- Do not try to remove an electromagnetic CRT from its yoke until you have discharged the high voltage from the anode connector (hole).
- Never hold a CRT by its neck.
- When you set a CRT down, always place its face down on a thick piece of felt, rubber, or smooth cloth.
- Always handle the CRT gently. Rough handling or a sharp blow on the service bench can displace

the electrodes within the tube, causing faulty operation.

- Wear safety glasses and gloves whenever you handle a CRT.

RADIOACTIVE ELECTRON TUBES

Electron tubes containing radioactive material are common to radar equipment. These tubes are known as Transmit-Receive (TR), antitransmit-receive (ATR), spark-gap, voltage-regulator, gas-switching, and cold-cathode gas-rectifier tubes. Some of these tubes contain radioactive material that has a dangerous intensity level. Such tubes are so marked according to military specifications. In addition, all equipment containing radioactive tubes must have a standard warning label attached where maintenance personnel can see it as they enter the equipment.

As long as these electron tubes remain intact and are not broken, no great hazard exists. However, if they are broken, the radioactive material may become a potential hazard.

The radioactivity in a normal collection of electron tubes in a maintenance shop does not approach a dangerous level, and the hazards of injury from exposure are slight. However, at major supply points, the storage of large quantities of radioactive electron tubes in a relatively small area may create a hazard. If you work in an area where a large quantity of radioactive tubes is stored, you should become thoroughly familiar with the safety practices contained in *Radiation Health Protection Manual*, NAVMED P-5055. By complying strictly with the prescribed safety precautions and procedures of this manual, you should be able to avoid accidents and maintain a work environment that is conducive to good health.

The hazardous materials information system (HMIS) contains a listing of radioactive tubes, along with proper stowage techniques and disposal procedures. Afloat Supply Procedures, NAVSUP P-485 contains detailed custody procedures. Be sure you use proper procedures whenever you dispose of a radioactive tube. Also, be aware that federal and state disposal regulations may vary.

Any time you handle radioactive electron tubes, take the following precautions:

1. Do not remove a radioactive tube from its carton until just before you actually install it.
2. When you remove a tube containing a radioactive material from equipment, place it in an appropriate carton to keep it from breaking.
3. Never carry a radioactive tube in your pocket, or elsewhere on your person, in such a way that could cause the tube to break.
4. If you do break a radioactive tube, notify the appropriate authority and obtain the services of qualified radiological personnel immediately. The basic procedures for cleaning the area are covered in the EIMB, *General*, Section 3. If you are authorized to clean the area, get a radioactive spill kit with all the materials to clean the area quickly and properly. The ship must have at least one radioactive spill disposal kit for its electronic spaces. It may have more, depending on the number and location of spaces in which radioactive tubes are used or stored. Each kit should contain the following items:

   - Container—Must be large enough to hold all cleanup materials and pieces of broken radioactive tubes and must be airtight. A three-pound coffee can with a plastic lid or 30/50 caliber ammo box is an acceptable container. The container must be clearly marked "RADIOACTIVE SPILL DISPOSAL KIT."
   - Rubber gloves—Two pairs of surgical latex gloves to prevent contact with contaminated material.
   - Forceps or hemostats—Used for picking up large pieces.
   - Masking tape—One roll of 2-inch-wide tape for picking up small pieces.
   - Gauze pads or rags—One stack of 4-inch gauze pads (50 pads or more) for wiping down the area. **Do NOT use sponges.**
   - Container of water—A small container of water (approximately 2 ounces) in an unbreakable container, for wetting the gauze pads or rags.
   - Boundary rope and appropriate signs—Used for marking the contaminated area.
   - Respirator—With filters that are specific for radionuclides.

- Radioactive material stickers—For labeling the material to be disposed of. (These can be made locally).
- Two 12-inch plastic bags—For containing the used material.
- Procedures—Step-by-step cleanup procedures.
- Other items recommended by the type commander and the fleet training group.

5. Isolate the immediate area of exposure to protect other personnel from possible contamination and exposure.
6. Follow the established procedures set forth in NAVMED P-5055.
7. Do not permit contaminated material to contact any part of your body.
8. Avoid breathing any vapor or dust that may be released by tube breakage.
9. Wear rubber or plastic gloves at all times during cleanup and decontamination procedures.
10. Use a HEPA filtered vacuum cleaner (with an approved disposal collection bag) to remove the pieces of the tube. The vacuum cleaner should be designated for "Spill Response" or "For Cleanup of Radioactive Materials ONLY" and use the standard magenta/yellow markings for labeling. If a vacuum cleaner is not available, use forceps and/or a wet cloth to wipe the affected area. In this case, be sure to make one stroke at a time. DO NOT use a back-and-forth motion. After each stroke, fold the cloth in half, always holding one clean side and using the other for the new stroke. (Dispose of the cloth in the manner stated in item 14.)
11. Do not allow any food or drink to be brought into the contaminated area or near any radioactive material.
12. Immediately after leaving a contaminated area, if you handled radioactive material in any way, remove any contaminated clothing. Also wash your hands and arms thoroughly with soap and water and rinse them with clean water.
13. Immediately notify a medical officer if you sustain a wound from a sharp radioactive object. If a medical officer cannot reach the scene immediately, stimulate mild bleeding by applying pressure about the wound and using suction bulbs. DO NOT USE YOUR MOUTH. If the wound is a puncture type, or the opening is small, make an incision to promote free bleeding, and to enable cleaning and flushing of the wound.
14. When you clean a contaminated area, seal all debris, cleaning cloths, and collection bags in a container such as a plastic bag, heavy wax paper, or glass jar. Place the container in a steel can until it can be disposed of properly. Decontaminate, using soap and water, all tools and implements you used to remove a radioactive substance. Monitor the tools and implements for radiation with an authorized radiac set. They should emit less than 0.1 MR/HR at the surface. (MR/HR is the abbreviation for milliroentgen/hour,which is defined as a unit of radioactive dose of exposure.)

References to Consult Concerning Radioactive Tubes

The following is a basic list of publications conerning the handling and use of radioactive tubes.

– *Department of Defense Hazardous Materials Information System (HMIS)*, DOD 6050.1-L

– *Radiation Health Protection Manual*, NAVMED P-5055

– *Afloat Supply Procedures,* NAVSUP P-485

– *EIMB, General*

– *EIMB, Radiac*

– *Safety Precautions for Forces Afloat*

– *Naval Ships' Technical Manual*, Chapter 400

Technical Assistance

For technical assistance and advice regarding identification, stowage, or disposal of radioactive tubes, contact:

Officer In Charge
Naval Sea Systems Command Detachment
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X-RAY EMISSIONS

X-rays may be produced by high-voltage electronic equipment. X-rays can penetrate human tissue and cause both temporary and permanent damage. Unless the dosage is extremely high, there will be no noticeable effects for days, weeks, or even years after the exposure.

The sources of these x-rays are usually confined to magnetrons, klystrons, and CRTs. Where these types of components are used, you should not linger near any equipment on which the equipment covers have been removed. Klystrons, magnetrons, rectifiers, or other tubes that use an excitation of 15,000 volts or more may emit x-rays out to a few feet, thus endangering you or other unshielded personnel standing or working close to the tubes.

If you must perform maintenance on x-ray emitting devices, take the following precautions:

- Observe all warning signs (fig. 3-9) on the equipment and all written precautions in the equipment technical manual.
- Do NOT bypass interlocks that prevent the servicing of operating equipment with the x-ray shield removed, unless the technical manual requires you to do so.
- Be sure to replace all protective x-ray shielding when you finish the servicing.

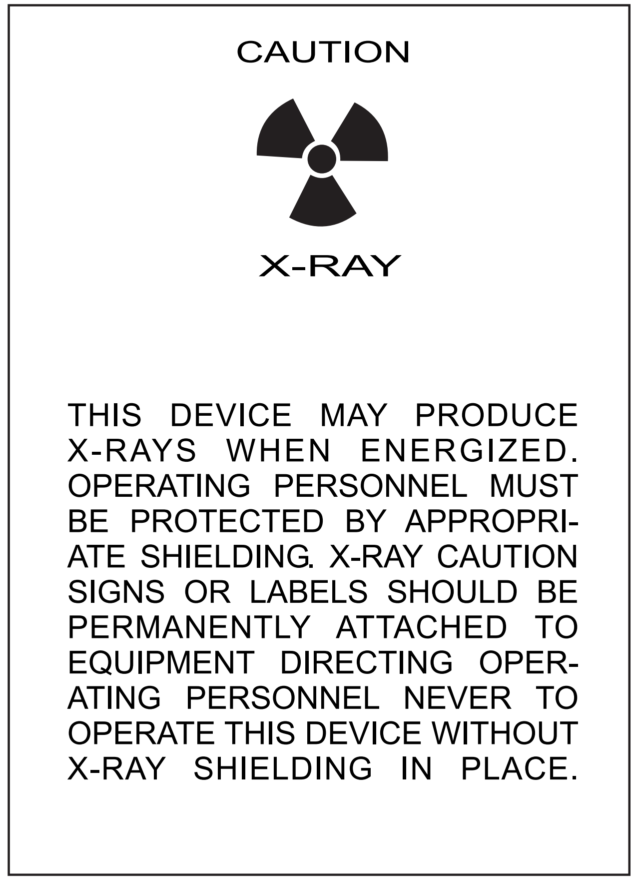

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Figure 3-9.—X-ray caution label.

SUMMARY

This chapter has presented radar safety measures you are expected to practice in your daily work. As with electrical and electronic safety, the greatest danger you will face as a Fire Controlman is becoming too familiar with the safety hazards you will face. COMPLACENCY KILLS! Radio frequency energy is not the only hazard associated with working around radar. Working aloft has its own set of hazards. Be aware of your environment and other evolutions that are happening around you. It is your responsibility to know what warning signs mean and where they should be posted. Remember, as a Fire Controlman, you have a responsibility to yourself and to your shipmates to always be alert to detect and report hazardous work practices and conditions.

APPENDIX I

REFERENCES USED TO DEVELOP THIS NRTC

NOTE: Although the following references were current when this NRTC was published, their continued currency cannot be assured. When consulting these references, keep in mind that they may have been revised to reflect new technology or revised methods, practices, or procedures; therefore, you need to be sure that you are studying the latest references.

Chapter 1

Combat Systems Technical Operations Manual (CSTOM)

Electronics Installation and Maintenance Book-General, NAVSEA SE000-00-EIM-100, Electronics Installation and Maintenance Book (EIMB), Naval Sea Systems Command, Washington, DC, 1983.

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Navy Electricity and Electronics Training Series (NEETS), Module 10, *Introduction to Wave Propagation, Transmission Lines, and Antennas*, NAVEDTRA B72-10-00-93, Naval Education and Training Program Management Support Activity, Pensacola, FL, 1993.

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Navy Electricity and Electronics Training Series (NEETS), Module 18, *Radar Principles,* NAVEDTRA 172-18-00-84, Naval Education and Training Program Development Center, Pensacola, FL, 1984.

Chapter 2

A1-F18AC-744-100, *Organizational Maintenance Principles of Operation Forward Looking Infrared System, Chapter 3, Principles of Operation* (0801-LP-1022-2428)

Harpoon US Navy Fact File (Harpoon Missile)website:
http://www.chinfo.navy.mil/navpalib/factfile/missile/wep-harp.html

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www.fas.org/man/dod-101/sys/smart/agm-84.htm

OP 3541, *Volume 1, Revision 2, AN/SPG-51D* (0610-LP-354-1129)

Op 3594, Volume 7A, *HARPOON*

OP 4350, *Transmitter, Control and Power Supply for AN/SPG-51D*

RAM website:
www.raytheon.com/products/ram/index.html

RAM (Rolling Air Fram missile (RAM) website:
http://www.chinfo.navy.mil/navpalib/factfile/missile/wep-ram.html

SE213-UE-MMO-010, *Radar Set AN/SPS-48E*; *Volume 1 Part 1, Radar set, Chapter 1, General Information* (0910-LP-586-4200)

SE213-VC-MMO-010, *Radar Set AN/SPS-52C; TM Volume 1, Chapters 1 and 2* (0910-LP-064-5800)

SW221-JO-MMO-010, *Close-In Weapon System, Mk 15, Mod 11-14 (PHALANX); Introduction to CIWS, Volume 1* (0640-LP-167-5800)

SW230-AO-SOM-060, *Target Acquisitioning System (TAS) Mk 23; Operations Manual for CV/CVN class, Integrated with CDS* (0640-LP-168-1900)

SW261-SA-GYD-010, *Ship Self Defense System (SSDS); Mk 1 Mod 0, Installation and Checkout Support Guide* (0640-LP-021-6420)

SW272-AM-AEG-010, *AEGIS RADAR SYSTEM for SPY-1D; Description, Operation and Maintenance* (0640-LP-013-4590)

SW272-AJ-AEG-020, *AEGIS RADAR SYSTEM HANDBOOK for SPY-1B/D; B/L 5.3/3A* (0640-LP-021-7570)

SW279-EJ-AEG-010, *AEGIS ANTENNA GROUP for SPY-1D; Description and Operation* (0640-LP-013-4490)

TE660-AX-PDD-230*, AN/SYS-2 (V) 1 Radar Satellite Simulation Program; Program Description Document, Volume 23; AN/SPS-48E* (0910-LP-148-2900)

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Contributing Commands/Facilities

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FC "A" School

Naval Air Warfare Center (NAWC) Weapons Division, Point Mugu

Naval Air Warfare Center Weapons Division (NAWCWD), Fleet Help Desk, China Lake

Naval Research Laboratory (NRL)

Naval Sea Systems Command (NAVSEASYSCOM) NAVY SEA Test and Evaluation Office

Naval Surface Warfare Center, Carderock Division (NSWCCD) Smart Ship Program

Naval Surface Warfare Center, Dahlgren Division (NSWCDD)

Surface Warfare Officer School (SWOS)

INDEX

ASSIGNMENT 1

Textbook Assignment: "Introduction to Basic Radar Systems," chapter 1, pages 1-1 through 1-22 and "Fire-Control Systems," chapter 2, pages 2-1 through 2-9.

NOTE: IN THIS ASSIGNMENT, FIGURES MENTIONED IN THE QUESTIONS ARE FOUND IN THE TEXT.

1-1. The term "radar" is an acronym made from the words

1. radio, detection, and roaming
2. radio, distance, and ranging
3. radio, detection, and ranging
4. radio, detection, or ranging

1-2. Radar surface angular measurements are normally made from which direction?

1. North/south
2. East/west
3. Counter-clockwise from true north
4. Clockwise from true north

1-3. The angle measured clockwise from true north in the horizontal plane defines which of the following terms?

1. True bearing/azimuth
2. True horizontal plane
3. Line-of-sight range
4. True north

1-4. What is the primary limiting factor for maximum range of a pulse-radar system?

1. Carrier frequency
2. Peak power of transmitted pulse
3. Receiver sensitivity
4. Pulse-repetition frequency

1-5. The angle between the centerline of the ship and a line pointed directly at a target is known by what term?

1. Relative bearing
2. True bearing
3. Angle north
4. Angular bearing

1-6. What is the most common method used to transmit radar energy?

1. Continuous-wave
2. Pulse-modulation
3. Doppler-wave
4. Frequency-modulation

1-7. What characteristic of continuous-wave radar makes it difficult, if not impossible, to get accurate range measurements?

1. Doppler effect
2. Missile guidance
3. Illumination
4. No specific stop time

1-8. Range resolution is defined as the ability of a radar to perform what action?

1. Separate objects at the same range, but slightly different bearings
2. Distinguish between two targets on the same bearing, but at slightly different ranges
3. Separate objects at different ranges, but slightly different bearings
4. Distinguish between two targets on different bearings, but at the same range

1-9. Which of the following factors affect(s) radar performance?

1. Operator skill
2. Electronic Attack activity
3. Weather conditions
4. All of the above

1-10. According to figure 1-4, what is considered the heart of a pulse radar system?

1. Synchronizer
2. Antenna system
3. Transmitter
4. Duplexer

1-11. A certain amount of time is required for a duplexer to disconnect the antenna from the receiver and connect it to the transmitter. What is this switching time called?

1. Receiver recovery time
2. Fast reaction time
3. Detection time
4. Transmitter recovery time

1-12. What radar subsystem is used to convert RF echoes to a lower frequency?

1. Superheterodyne receiver
2. Antenna system
3. Duplexer
4. Transmitter

1-13. Figure 1-5 shows four basic radar displays. Which of the displays uses your own ship as the center of the display?

1. Type A
2. Type B
3. Type P
4. Type E

1-14. An automobile headlight is similar, in shape, to what type of radar reflector?

1. Truncated
2. Parabolic
3. Orange peel
4. Banana peel

1-15. Radar antennas are designed using well-known optical design techniques. Which of the following radar characteristics allows a radar antenna to be designed in this way?

1. Radar operates in the microwave region of the electromagnetic spectrum
2. Radar operates in the ultraviolet region of the electromagnetic spectrum
3. Radar operates in the VLF region of the electromagnetic spectrum
4. Radar operates in the infrared region of the electromagnetic spectrum

1-16. What general characteristic of a horn radiator is determined by the size of its mouth opening?

1. Symmetry
2. Relativity
3. Conductivity
4. Directivity

1-17. Which of the following design actions can be used to eliminate feedhorn shadows?

1. Making the horn smaller
2. Putting the horn behind the reflector
3. Offsetting the horn from the center of the reflector
4. Making the reflector smaller

1-18. Which of the following antennas are lens type antennas?

1. Conducting and dielectric
2. Optical and electro-optical
3. Flatplane and spherical plane
4. Microwave and plane wave

1-19. In a delay lens, the amount of delay is dependent on what characteristic?

1. Thickness
2. Dielectric constant
3. Angle of reflection
4. Angle of incidence

1-20. Which of the following elements can be used in an array antenna?

1. Slots
2. Dipoles
3. Horns
4. Each of the above

1-21. In an array antenna, what determines the position of the beam?

1. The relative phase between the elements
2. The relative amplitude between the elements
3. The total amplitude of the elements
4. The scan motor

1-22. Which of the following adverse effects in a small radome is caused by reflected power?

1. Beam deflection
2. Transmission loss
3. Antenna mismatch
4. Secondary effects

1-23. What level of maintenance do FC's normally perform on radomes?

1. Ship's 2M
2. Factory repairs
3. Technical repairs
4. Preventive maintenance

1-24. Which of the following equipment is NOT part of the control group for a radar system?

1. AN/UYK-43 computer
2. AN/BPS-15 radar group
3. RD-358A(V)/UYK magnetic tape unit
4. OJ-535 data terminal set

1-25. Every radar system requires a certain amount of support equipment to operate properly. Which of the following equipment is support equipment?

1. SF6 gas canister
2. Step-down transformer
3. Frequency converter
4. Each of the above

1-26. What is the primary purpose of a stable element?

1. To measure any deviation of a director from the vertical plane
2. To measure approximate deviation from any optical equipment
3. To measure any deviation of a launcher from the horizontal plane
4. To measure approximate deviation from any radar antenna

1-27. What equipment listed below does NOT comply with the Joint Electronics Type Designation System (JETDS)?

1. AN/SPF-40
2. AN/SPS-48E
3. AN/SPG-60
4. AN/SPQ-9B

1-28. What is the primary function of air-search radar?

1. To maintain a 360-degree surveillance
2. To provide security against attacks
3. To provide information for aircraft control
4. To determine aircraft altitude

1-29. The AN/SPY-1 series radar is a multi-dimensional radar. How does it differ from air-search radar?

1. It has a wider vertical beamwidth
2. It has a narrower vertical beamwidth
3. It has a lower transmitting frequency
4. It has a lower output power

1-30. Missile guidance systems consist of two separate systems. An attitude control system is one of those systems. What is the other system?

1. Rocket motor control system
2. Rocket motor thrust system
3. Flight yaw control system
4. Flight path control system

1-31. According to figure 1-17, which of the following components is NOT part of the control subsystem?

1. Computer detector
2. Servo motor
3. Receiver
4. Control surface

1-32. The Standard SM-2 missiles use three phases of guidance. What are they?

1. Boost, dropoff, terminal
2. Boost, midcourse, terminal
3. Guided, midcourse, terminal
4. Unguided, midcourse, terminal

1-33. Which of the following missiles should follow the guidance path shown in figure 1-18B?

1. Standard SM-1 (ER)
2. Standard SM-1
3. Standard SM-2 (MR)
4. Standard SM-2 (ER)

1-34. The initial phase of a missile flight lasts how long?

1. Until the target is destroyed
2. Until the booster recharges
3. Until the booster burns up its fuel
4. Until the target manuevers

1-35. What phase of missile guidance requires fast response to guidance signals?

1. Final phase
2. Boost phase
3. Initial phase
4. Midcourse phase

1-36. In an inertial guidance system, what devices control the missile?

1. Accelerometers
2. Accelerators
3. Fin stabilizers
4. Yaw stabilizers

1-37. A beam-rider missile is most effective against which of the following types of targets?

1. Outgoing and long-range
2. Incoming and long-range
3. Incoming and medium-range
4. Outgoing and long-range

1-38. Homing guidance is the most accurate method of missile guidance. What gives it this ability?

1. RF waves
2. Reflected energy
3. Magnetic field energy
4. Guidance error signals

1-39. According to figure 1-21, which of the following terms best describes guidance for a HARPOON missile?

1. Passive homing
2. Semi-active homing
3. Active homing

1-40. Which of the following factors is a drawback of semi-active homing?

1. During its use, the ship is not free to use SMS missiles
2. Its use keeps the system tied to a single target
3. It can only be used with SEASPARROW missiles
4. It can only be used with STANDARD SM-1 missiles

1-41. Figure 1-21 illustrates the different homing guidance methods. Which method is used for a STANDARD ARM missile?

1. Passive homing
2. Semi-active homing
3. Active homing

1-42. What type of data is primarily used in fire-control radar?

1. Continuous positional data
2. Intermittent horizontal data
3. Target resolution data
4. Continuous ship position data

1-43. Which of the following is the correct sequence for modes of radar operation?

1. Designation, acquisition, and search
2. Designation, direction, and search
3. Designation, direction, and track
4. Designation, acquisition, and track

1-44. Search radar is used for what operation of the fire-control problem sequence?

1. Track phase
2. Detection
3. Prediction
4. Evaluation

1-45. Continuous, accurate target position is available during what stage of fire-control problem sequencing?

1. Acquisition and tracking
2. Launcher positioning
3. Missile guidance
4. Evaluation

1-46. Which of the following operations is NOT performed after target detection and acquisition?

1. Establishing a track LOS
2. Determining launcher position angle
3. Positioning the gun mount
4. Establishing a targets initial position

1-47. During the acquisition and tracking phase, why are radar indications of a target considered as instantaneous, present target positions?

1. RF energy travels at the speed of light
2. Target ranges are relatively small
3. Both 1 and 2 above
4. Target speed is fast

1-48. According to Table 1-2, which of the following radar systems should be used during the designation phase of the fire-control problem sequence?

1. Mk 95 radar
2. Sps 48E
3. Mk 1
4. HF Surface Wave

1-49. Although fire-control radar is more accurate, initial detection of a target is done with search radar. Which of the characteristics listed below enable(s) search radar to initially detect a target?

1. Narrow beam width
2. Wide beam width
3. Long-range 360 degree coverage
4. Both 2 and 3 above

1-50. Which system below is a search radar that an FC might work with in today's Navy?

1. AN/SPS-40(V)
2. SLQ-32(V)3
3. AN/SPS-49
4. AN/SPS-48E

1-51. The AN/SPS-48E radar is a long-range, three-dimensional radar that FC's work with. How does this radar provide contact range, height, and bearing information?

1. By using D/E band frequency scanning
2. By using E/H band short-dwell time
3. By using E/F band frequency scanning
4. By using D/E band short-dwell time

1-52. Which of the following modes is NOT an SPS-48 radar mode?

1. Equal Angle Coverage
2. Maximum Frequency Management
3. Maximum Energy Management
4. Adaptive Energy Management

1-53. The AN/SPS-48 radar is found on what type(s) of ship?

1. NIMITZ class carriers
2. LCC class amphibious ships
3. ENTERPRISE class carriers
4. All of the above

1-54. Fire-control radar is normally part of larger systems. Which of the following systems are larger gun or missile systems that are associated with fire-control radar?

1. GFCS
2. FCCS
3. GMCM
4. MFCC

1-55. Which of the following systems is/are found on board the USS *Paul Hamilton*?

1. SPY-1 radar system
2. Mk 99 MFCS
3. Mk 86 GFCS
4. All of the above

1-56. The Mk 7 Aegis FCS is found on board ARLEIGH BURKE class destroyers and TICONDEROGA class cruisers. Which of the following radar systems should you find on board one of these ships?

1. SSDS
2. SPY-1
3. Mk 92
4. CAS

1-57. In reference to figure 2-4, which of the following is NOT a weapon or sensor found on an AEGIS class cruiser?

1. AN/SPS-49 radar
2. Mk 41 vertical launching tubes
3. AN/SPS-40E radar
4. AN/SPG-62 illuminators

1-58. The Mk 99 MFCS provides terminal guidance control for which of the following missiles?

1. TOMAHAWK cruise missile
2. SM-2 anti-air missile
3. SM-1 extended range missile
4. Stinger missile

1-59. What type of radar is the AN/SPG-62?

1. Long-range search radar
2. Short-range tracking radar
3. Missile guidance radar
4. Gun illumination radar

1-60. Which of the following weapons is controlled by the Mk 86 GFCS?

1. Mk 45 5-inch gun
2. Mk 75 3-inch gun
3. Mk 13 missile launcher
4. Mk 45 8-inch gun

1-61. Which of the following radar systems enable the Mk 86 GFCS to support AW gun engagements?

1. CAS and Mk 23 TAS
2. STIR and CAS
3. AN/SPG-9B and AN/SPQ-9A
4. AN/SPQ-9 and Mk 23 TAS

1-62. The AN/SPQ-9B radar can track air and surface targets simultaneously. What characteristics allow it to do this?

1. Real-time signal and data processing
2. Low resolution and narrow beam radar
3. Raw video and azimuth video reference
4. Variable-time signal and beam processing

1-63. What modes of operation does the AN/SPQ-9B have?

1. Air, surface, and beacon
2. Air, surface, and beam
3. Detection and acquisition
4. High scan and low scan

1-64. What mode of the AN/SPQ-9B radar uses the pulse-doppler radar?

1. Surface
2. Detection
3. Air
4. Beam

1-65. The AN/SPQ-9B radar is found on board which of the following ship types?

1. SPRUANCE class destroyers
2. TICONDEROGA class cruisers
3. SAN ANTONIO class amphibious ships
4. All of the above

1-66. The Mk 23 TAS integrates various subsystems. Which of the following subsystems is NOT part of that integration?

1. Two-dimensional air-search radar
2. Long-range threat evaluation console
3. IFF subsystem
4. Display subsystem

1-67. What is the primary weapon controlled by the Mk 91 missile fire control system?

1. SEASPARROW missile
2. Mk 45 gun
3. HARPOON missile
4. Close-in weapon system

1-68. The Mk 91 missile fire control system uses which of the following consoles?

1. Firing officer console only
2. Signal data processor console only
3. Radar set console only
4. Advanced display system console

1-69. Which of the following radar systems is NOT part of the Mk 91 fire control system?

1. Mk 95 illuminator
2. Mk 23 target acquisition system
3. Mk 157 discriminator
4. AN/SPQ-9 series radar

1-70. Which of the following ship classes uses the Combined Antenna System?

1. TICONDEROGA class cruisers
2. LHA class amphibious ships
3. PERRY class frigates
4. SEAWOLF class submarines

1-71. In reference to figure 2-8, where is the STIR antenna located on a PERRY class frigate?

1. On the forward bullnose
2. On the aftship O-2 level
3. On the forecastle main deck
4. On the midship O-2 level

1-72. The Mk 15 Phalanx Close-In Weapon System has two primary modes of operation. What are they?

1. Air ready and manual
2. Recommend fire and manual
3. Remote control and manual
4. Automatic and manual

1-73. What is the principal air threat to U. S. naval surface ships?

1. Anti-ship cruise missiles
2. Low, slow, or hovering aircraft
3. Low altitude enemy aircraft

1-74. Which of the following is **NOT** a capability of the MK 31 RAM system?

1. Fire and forget missile
2. No self-destruct mode
3. Slow reaction time
4. To destroy anti-ship cruise missiles

1-75. The MK 44 Missile Round Pack has what total number of cells?

1. 16
2. 21
3. 24
4. 27

ASSIGNMENT 2

Textbook Assignment: "Fire Control Systems," chapter 2, pages 2-9 through 2-16 and "Radar Safety," chapter 3, pages 3-1 through 3-17.

2-1. The Ship Self-Defense System (SSDS) integrates and coordinates what equipment on board non-AEGIS class ships?

1. Existing sensors and weapons
2. Special computer programs
3. Operator stations
4. All of the above

2-2. SSDS is the integration element of the entire combat system program, including all weapons and sensors. Which of the following is NOT a purpose of SSDS?

1. To improve reaction time from detect to engagement in less than 60 seconds
2. To improve the performance of weapons/sensors beyond normal stand-alone capability.
3. To improve the integration and coordination of all weapons and sensors in order to provide quick reaction combat capability
4. To improve the capability to engage multiple targets and quick response against anti-ship cruise missiles

2-3. Which of the following systems is an SSDS interface on a non-AEGIS class ship?

1. AN/SPS-49 air search radar
2. AN/SPG-62 illuminator
3. AN/SPQ-9B fire control radar
4. AN/SPY-1 multi-dimensional radar

2-4. Which of the following systems uses heat or light as a source for target detection?

1. Fire control radar
2. Close-in weapon system
3. Optronic system
4. Air search radar

2-5. The Thermal Imaging Sensor System (TISS) provides surface and air target data to combat systems via an electro-optical system. TISS also has which of the following capabilities?

1. Good night detection and identification
2. Mine detection
3. Both 1and 2 above
4. Aid to navigation

2-6. Which of the following sensors is/are a part of upcoming developments in radar?

1. High frequency surface wave
2. Multi-function radar
3. Volume search radar
4. All of the above

2-7. What is the definition of a warning status of yellow?

1. Hostilities probable
2. Hostilities imminent
3. Hostilities detected
4. Hostilities displayed

2-8. The Tactical Action Officer (TAO) is responsible for which of the following actions in the absence of the commanding officer?

1. The proper employment of the ship's weapons systems
2. The proper navigation of the ship through friendly waters
3. The proper employment of the ship's auxiliary systems
4. The proper use of consoles in the combat information center

2-9. During a Detect-to-Engage scenario, what is the first equipment to detect and identify a threat?

1. A wide band ESM receiver
2. A fire control radar
3. An IFF interrogator
4. A narrow band navigation radar

2-10. The ship's 2-D air search radar, with the help of the ESM receiver, helps to localize the incoming threat. What tactical information does localizing the threat give you?

1. An accurate bearing only
2. An accurate range and bearing
3. An accurate range only
4. An accurate range, bearing, and altitude

2-11. What feature of the ship's 3-D radar leads you to believe that the threat consists of only one aircraft?

1. The bearing resolution of the pulse-compressed radar
2. The elevation resolution of the pulse-compressed radar
3. The resolution of the ESM sensors
4. The range resolution of the pulse-compressed radar

2-12. According to the Rules of Engagement (ROE) in effect, you have determined hostile intent based on a target's action. At this point you should prepare to defend your ship against what type of attack?

1. Probable
2. Conceivable
3. Comprehensible
4. Imminent

2-13. After you inform the Anti-Air Warfare Commander of a target's hostile intent, he places your ship in Air Warning Red. What does Air Warning Red mean?

1. Attack is imminent
2. Attack is probable
3. Attack is on hold
4. Attack is in progress

2-14. Once a target is close enough to be detected by your weapons system, the fire control computer uses the target's course and speed to compute where your missile will engage the target. What is the term used for this place of engagement?

1. Predicted engagement envelope
2. Predicted intercept envelope
3. Predicted intercept point
4. Predicted engagement point

2-15. What verbal command authorizes the launching of a missile at a hostile target?

1. "Batteries release"
2. "Batteries charged"
3. "Fire all batteries"
4. "Fire all weapons"

2-16. From which of the following sources do you confirm that the target has been destroyed or neutralized?

1. Ship's lookouts
2. Ship's sensors
3. Anti-air warfare commander
4. ESM equipment only

2-17. Which of the following functions is part of the modern fire control problem?

1. Informing the warfare commander of the threat
2. Confirming target resolution
3. Making a weapon selection
4. Making equipment ready for tracking

2-18. What is the ultimate goal of all subsystem components in solving the fire control problem?

1. To quickly locate the target
2. To neutralize the target
3. To detect the target
4. To select the right weapon

2-19. There are three phases involved in target detection by a weapon system. What is the second phase?

1. Surveillance and detection
2. Interpret the behavior of the target
3. Measuring or localizing the target's position
4. Classifying the target

2-20. Which phase uses either reflected energy or received energy emitted from the target to detect a target?

1. First
2. Second
3. Third
4. Fourth

2-21. In tracking a target, a collection of motors and position-sensing devices called a servo system helps to successfully engage a target. The operation of such a system is based on what inherent concept?

1. Error reduction
2. Feedback
3. Zeroing
4. Rate reduction

2-22. What is the definition of “system error”?

1. The difference between where the sensor is located and where the target is going
2. The difference between where the target is pointing and where the target is actually going
3. The difference between where the sensor is pointing and where the sensor is located
4. The difference between where the sensor is pointing and where the target is actually located

2-23. What devices are used in servo systems to detect the position of and to control the movement of power drives?

1. Gun mounts
2. Missile launchers
3. Optical encoder
4. Radar antennas

2-24. The effective engagement and neutralization of a target requires that a destructive mechanism, such as a missile warhead, be delivered to the vicinity of the target. Which of the following factors should be considered in the design of an effective destructive mechanism?

1. Propulsion system
2. Fuzing mechanism
3. Warhead design
4. All of the above

2-25. Which of the following is **NOT** a characteristic of the Harpoon Missile?

1. Anti-ship cruise missile
2. Land attack
3. All weather missile
4. Over-the-horizon range

2-26. What Harpoon missile feature contains a fuel tank for JP-10 fuel?

1. Control
2. Warhead
3. Sustainer
4. Guidance

2-27. The Harpoon Booster separates from the missile approximately how many kyds down range?

1. 1
2. 2
3. 3
4. 4

2-28. Which of the following Harpoon firing salvos uses one platform while shooting at least 2 missiles to overwhelm targets defenses?

1. Ripple
2. STOT
3. DTOT
4. BTOT

2-29. Which of the following is **NOT** a characteristic of the Tomahawk Missile?

1. Low altitude
2. Land attack
3. Short range
4. Conventional warhead

2-30. Which of the following is **NOT** a component of the Tomahawk Weapon System (TWS)?

1. AUR
2. ABL
3. VLS
4. APS

2-31. What variant of Tomahawk dispenses bomblets?

1. TLAM-A
2. TLAM-B
3. TLAM-C
4. TLAM-D

2-32. What is the purpose of your command’s bombarding you with safety slogans, rules, and procedures?

1. To keep you alive and well
2. To improve your morale
3. To keep you busy
4. To give you something to do

2-33. Being safety conscious means to approach every job from a safety point of view.

1. True
2. False

2-34. Radio Frequency Radiation (RFR) is one of the hazards associated with radar operation. Which of the following areas around a radar antenna should you consider to be an RFR hazard?

1. The front
2. The sides
3. The rear
4. All of the above

2-35. If you suspect any injury or excessive exposure to radiation which of the following individuals should you contact?

1. Your leading petty officer
2. Your ship's doctor or corpsman
3. Your division chief
4. All of the above

2-36. Whenever you work around radar equipment, you should observe which of the following safety precautions?

1. Do not inspect feedhorns when they are emitting RFR
2. Observe all RADHAZ warning signs
3. Ensure that radiation hazard warning signs are available and used
4. All of the above

2-37. Scientific studies have shown that people cannot easily sense electromagnetic radiation (EMR). What EMR frequency range presents a hazard to humans?

1. 10 Hz to 300 Hz
2. 10 kHz to 300 GHz
3. 10 THz to 300 THz
4. 1000 Hz to 3000 Hz

2-38. Hazards of Electromagnetic Radiation to Ordnance (HERO) is one category of radiation hazards. What are the other two categories?

1. HERP and HERD
2. HERF and HERR
3. HERD and HEED
4. HERP and HERF

2-39. What type of devices can actuate prematurely in ordnance systems due to RFR?

1. Electro-optical devices
2. Electromagnetic devices
3. Electroexplosive devices
4. Electromechanical devices

2-40. When are ordnance systems most susceptible to RFR energy?

1. During loading only
2. During unloading only
3. During assembly
4. During disassembly only

2-41. The radiation hazard HERO can be broken down into three classifications. In which of the following conditions is an item considered to be HERO unsafe?

1. The item is being assembled
2. The item contains
3. The item is sufficiently shielded from
4. The item, through testing, has been proven to be adversely affected by

2-42. Which of the following publications will list your ship's specific requirements for HERO safety?

1. Naval Sea Systems Command instruction
2. EMCON bill
3. NAVSEA OP 3565
4. NAVAIR 16-1-529

2-43. Who is responsible for the implementation of HERO requirements?

1. Commanding officer
2. Executive officer
3. Safety officer
4. All hands

2-44. Which of the following publications lists specific guidance about fueling operations and radar on your ship?

1. EXCON bill
2. NAVSEA OP 3565
3. NAVELEX volume I

2-45. According to table 3-1 in the text, what is the maximum permissible exposure time limit for a fixed-beam hazard with the AN/SPY-1 radar transmitter?

1. 0.023 minute
2. 0.23 minute
3. 3.2 minutes
4. 6 minutes

2-46. Which of the following changes in frequency increases the likelihood of biological damage from RFR?

1. A decrease in frequency only
2. An increase in frequency only
3. Either an increase or decrease in frequency

2-47. A navigational radar with a frequency of 900 MHz may cause what type of damage, if any, to body tissues?

1. Minor damage
2. Damage to surface skin
3. Deep tissue damage
4. None

2-48. Which of the following parts of the electromagnetic spectrum can cause damage to the transparent lens of the eye?

1. Ultraviolet
2. Infrared
3. Radio frequency
4. All of the above

2-49. Permanent injury to the testicles can happen because of which of the following hazard conditions?

1. An extremely high dosage of RF
2. High exposure of RF for many years
3. Both 1 and 2 above

2-50. Shipboard radar has cutout switches for personnel safety due to radiation. Which of the following is a function of cutout switches?

1. They turn off the transmitter for certain bearings and elevations
2. They turn off the transmitter for certain bearings only
3. They turn off the transmitter for certain elevations only

2-51. The specific cutout zones for your radar are identified in which of the following publications?

1. NAVSEA OP 3565
2. Operational publications
3. DOD instruction 6055.11
4. Bureau of Medicine and Surgery publications

2-52. Which of the following is a symptom of a mild burn?

1. Slow healing injury
2. Odor of scorched skin
3. A tingling sensation
4. Hair standing up

2-53. A common source of RFR burns is crane hooks. Which of the following factors is the basis of these burns?

1. The location of the crane
2. Induced RFR voltage
3. The location of transmitters
4. The location of wire ropes

2-54. The careful use of frequency can reduce the RFR voltages induced into crane structures and rigging. Which of the following is a better approach for the prevention of RFR induced voltage injuries to personnel?

1. The use of RFR high voltage insulator links
2. The use of RFR personnel protectors
3. The use of RFR insulated gloves
4. The use of RFR cable

2-55. Which of the following is considered the greatest hazard associated with working aloft?

1. Dropping of objects
2. Asphyxiation from stack gasses
3. Electrical shock
4. Falling

2-56. Which of the following is a danger associated with static charges encountered by personnel working aloft?

1. RFR burns to the skin
2. High-voltage shock
3. Surprise of the shock may cause a fall
4. Electrical arcing

2-57. Because of the associated dangers, no one may go aloft without the permission of which of the following personnel?

1. Chief petty officer
2. Officer of the deck
3. Division officer
4. Department head

2-58. Which of the following documents must be properly completed before permission is given to go aloft?

1. Working check sheet
2. Working aloft check sheet
3. Under way check off list
4. In port work list

2-59. When your ship is underway, who must grant permission to go aloft?

1. Commanding officer
2. Safety officer
3. Officer of the deck
4. Master chief of the command

2-60. How often should the announcement "DO NOT ROTATE OR RADIATE ANY ELECTRICAL OR ELECTRONIC EQUIPMENT WHILE PERSONNEL ARE WORKING ALOFT" be made over the 1MC?

1. Every 15 minutes
2. Every 20 minutes
3. Every 30 minutes
4. Every 45 minutes

2-61. What document gives you specific instructions for your ship with regard to man aloft procedures?

1. Under way check off list
2. Master work list
3. Ship's Organization and Regulation Manual
4. Man Aloft Bill

2-62. Which of the following is NOT a general guideline for going aloft?

1. Stop work if the ship rolls more than 10 degrees
2. Make sure the climber sleeve is attached to a safety harness when the wind speed is in excess of 30 knots
3. Read all posted safety placards before you begin work
4. Wear personal protective gear for hazards other than RFR

2-63. After working aloft, FC3 Smith leaves some rags and tools unsecured and then goes to lunch. You are his supervisor and learn that the ship's helo will be flying right after lunch. What, if anything, should you be concerned about, knowing the above facts?

1. FOD
2. Rescheduling maintenance
3. Nothing

2-64. For your safety when going aloft you should wear an approved parachute type harness. Which of the following components is/are associated with this type of safety harness?

1. Safety lanyard
2. Tending line
3. Double lock snap hooks
4. All of the above

2-65. A "Danger High Voltage" warning sign should be posted at the entrance to compartments that contain which of the following equipment?

1. Equipment with shock hazards in excess of 30 volts
2. Equipment with shock hazards in excess of 500 volts
3. Equipment with exposed conductors with shock hazards in excess of 500 volts
4. Equipment with exposed conductors with shock hazards less than 30 volts

2-66. In which of the following locations should you post stack gas warning signs?

1. Near the bottom of each access ladder leading aloft
2. At the top of each ladder leading aloft
3. At the base of the antenna pedestal
4. All of the above

2-67. Your radar equipment has a 4-inch red line circling it. What type of sign should be posted for your equipment?

1. Type 1
2. Type 2
3. Type 3
4. Type 4

2-68. A RADHAZ safety sign is mounted on a hook insulator and warns personnel not to touch the wire/rigging above the insulator. What type of RADHAZ safety sign is it?

1. Type 1
2. Type 2
3. Type 3
4. Type 4

2-69. Which of the following types of fuel is NOT considered to have a HERF problem?

1. AVGAS
2. MOGAS
3. JP-5

2-70. The type 6 RADHAZ sign advises of hazards of electromagnetic radiation to ordnance. Which of the following publications gives guidance on type 6 signs?

1. EMCON bill
2. NAVSEA OP 3565
3. SORM
4. NAVSEA OP 4134

2-71. Which of the following instructions is NOT a proper instruction concerning a CRT?

1. Discharge the high voltage from the anode connector before removing the CRT from its yoke
2. Wear safety glasses and gloves when lifting the CRT by its neck
3. Always place CRT face down on a thick piece of felt, rubber, or smooth cloth
4. Avoid scratching or striking the surface

2-72. On a ship, each electronics space is supposed to have one radioactive disposal spill kit. Which of the following items should be in the spill kit?

1. A container, rubber gloves, and forceps
2. Masking tape, gauze pads, and a container of water
3. Respirator, radioactive material stickers, and procedures
4. All of the above

2-73. If an approved HEPA filtered vacuum is NOT available for cleaning up the broken pieces of a CRT, what is the approved alternate method for clean up?

1. Use forceps and a wet cloth with a firm back and forth motion
2. Use forceps and dry cloth with a careful patting motion
3. Use forceps and dry cloth with a circular motion
4. Use forceps and a wet cloth, making one stroke at a time

2-74. If you sustain a wound from a sharp radioactive object whom should you immediately notify?

1. Safety officer
2. Commanding officer
3. Medical officer
4. Officer of the deck

2-75. X-ray emissions can penetrate human tissue and cause both temporary and permanent damage. Which of the following types of equipment are sources of x-rays?

1. Magnetrons
2. Klystrons
3. CRTs
4. All of the above