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Determination and Elimination of Hazardous Microwave Fields Aboard Naval Ships

ZORACH R. GLASER AND GLENN M. HEIMER

Glaser

Abstract—A qualitative description of the way that the problems of radio frequency and microwave radiation hazards to personnel aboard Naval ships have been handled is presented. The prediction and measurement of microwave fields produced by typical equipment used for communication, command and control, surveillance, fire control, and naviagtion are discussed. A hazard evaluation survey conducted aboard a ficititious ship, which closely parallels that performed on actual ships, is described. Mentioned are the various methods and techniques used to define and control the potentially hazardous environment which is unique to the Navy.

CONCERN for the potential biological hazards resulting from nonionizing electromagnetic radiation (especially at microwave and radio frequencies) has increased significantly. This is evidenced by the recent Symposium on the Biological Effects and Health Implications of Microwave Radiation (Richmond, Va., September 17–19, 1969), the Meeting of the Health Physics Society devoted to Electronic Product Radiation and the Health Physicist (Louisville, Ky., January 28–30, 1970), the Microwave Hazards Seminar (Boston, Mass., December 11–12, 1969), the journal titled and devoted entirely to *Nonionizing Radiation*, and this special issue of MICROWAVE THEORY AND TECHNIQUES. The topics most discussed at these meetings included 1) the fact that the maximum permissible power density levels allegedly used by the Soviets are 2 to 3 orders of magnitude lower than the U. S. levels, 2) the possibility that certain biological factors may not have received sufficient attention when our maximum permissible power density levels were established, 3) the absence of standardization in the hazard calculation and measurement techniques (especially those used in research), and 4) the many unanswered questions which have arisen in connection with the observed biological effects and the reported clinical manifestations resulting from exposure to nonionizing radiation. Public attention to these problems has been heightened by the implications of Public Law 90-602, the "Radiation Control for Health and Safety Act of 1968."

The Navy has a unique (and long-standing) operational problem because shipboard personnel must necessarily work within fixed distances from RF and microwave-radiating antennas. Accidental injuries sustained by technicians in the early days of radar prompted research on the biological hazards by the mid 1940's [1]–[3]. The dangers from the premature activation of electroexplosive devices in ordnance items, damage to radio receiver crystals, and the ignition of aircraft fuel vapors have also received much consideration. The microwave equipment utilized by the Navy for communication, command and control, surveillance, counter measures, fire control, and navigation has increased (and more importantly, will most likely continue to increase) in power, range, and complexity, as well as in number.

In an effort to ensure the safety of personnel, the Navy provides limiting radiation hazard distances and maximum allowable exposure times for all radars in use by fleet units, air wings, and Naval shore activities [4]–[6], [19]. Table I is representative of the actual listings made available.

The Electromagnetic Survey Group of the Naval Ship Engineering Center (NAVSEC), U. S. Navy, has made power density and field strength measurements aboard a number of ships which represent all ship classes. The purpose of such a survey is to determine areas aboard the ship where RF radiation hazards to personnel exist under actual operational conditions. The survey data also is evaluated by NAVSEC for the fuel hazards portion of the Navy's Radiation Hazards Program, and by the Naval Weapons Laboratory, Dahlgren, Va., in connection with the Hazards from Electromagnetic Radiation to Ordnance (HERO) Program.

The maximum permissible average power density level[1] of 10 mW/cm^2 for continuous exposure of the human body, and an incident energy level[1] not in excess of 300 mJ/cm^2/30 s for intermittent exposure are the values against which the shipboard measurements are compared. Locations in which the measured radiation is in excess of the above "safe" levels are designated "hazard areas."

The surveys are conducted on "first of a class" ships, or when a significant modification occurs, in a ship's "radar suit." In addition, hazard prediction techniques have now been refined through the use of computers so that it is possible to predict, during the early stages of a ship's design, the presence and degree of hazard to be anticipated, and to incorporate safety provisions

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Z. R. Glaser is with the Biophysics Division, Naval Medical Research Institute, Bethesda, Md. 20014.

G. M. Heimer is with the Naval Ship Engineering Center, Department of the Navy, Hyattsville, Md. 20782.

[1] Values provided by the Bureau of Medicine and Surgery, U. S. Navy.

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TABLE I

LIMITING RF RADIATION HAZARD DISTANCES AND MAXIMUM ALLOWABLE EXPOSURE TIMES FOR TYPICAL SHIPBOARD EQUIPMENT [2] (RF HAZARD DISTANCES IN FEET)

Radar	Fixed Beam	Scanning	Rotating	Scanning and Rotating	Maximum Exposure Time in Seconds Per 30 Seconds, Inside Fixed Beam Hazard Distance
AN/BPQ-1	27	25	0	0	2
AN/BPQ-2					
guidance	45	—	—	—	1
search	65	—	8	—	0.5
AN/BPS-1	5	—	0	—	12
AN/BPS-2	0	—	0	—	30
AN/BPS-4	15	—	0	—	3
AN/SPG-34	0	—	—	—	30
AN/SPG-48	54	—	—	—	12
AN/SPG-49	660	—	—	—	1.5
AN/SPG-49A, B	440	—	—	—	1
AN/SPG-50	0	—	—	—	30
AN/SPN-5	4	—	0	—	25
AN/SPN-6	140	—	0	—	12
AN/SPN-8, 8A	10	0	—	—	20
AN/SPS-43	70	—	20	—	1.5
AN/SPS-43A	40	—	0	—	6
AN/SPS-46	0	—	0	—	30
AN/SPS-48	1150	0	0	0	2.5
AN/TPS-1D, 1G	30	—	0	—	15

Notes:

1) In determining the hazard distance for antennas rotating and/or scanning, either mechanically or electronically, an incident energy level of 300-mJ/30 s time interval is used. This is equivalent to continuous exposure to $10\ \mathrm{mW/cm^2}$/30 s.

2) A dash (—) indicates radar does not normally operate in this mode.

3) A zero (0) indicates that the radar is safe up to the swing circle of the antenna. It is not necessarily safe between the primary field and the reflector for the type of antenna.

4)

AN/BPQ( )	submarine radar, special—including missile guidance
AN/SPG( )	surface ship radar, fire control—missile or gun
AN/SPN( )	surface ship radar, navigation—including aircraft control
AN/SPQ( )	surface ship radar, special—including missile guidance
AN/SPS( )	surface ship radar, detecting and/or range and bearing
AN/TPS( )	transportable radar, detecting and/or range and bearing.

TABLE II

RADAR EQUIPMENT IN USE ON U.S.S. CHARLIE BROWN.

Equipment[a,b]	Use	Operates in the Frequency Range Designated as Band[c]
AN/SPS-70	height finder	S
AN/SPS-83	air search	P
AN/SPS-89	search	S
AN/SPG-99	fire control	X and C

[a] The average power output of these transmitters is in excess of 2 kW.

[b] The numbers in the equipment designation are fictitious.

[c] The following radar band designations are used.

Band Designation	Frequency Range (MHz)	Wavelength Range (cm)
P	220–390	133.3 –76.9
L	390–1550	76.9 –19.3
S	1550–5200	19.3 – 5.77
C	3900–6200	7.69 – 4.84
X	5200–10 900	5.77 – 2.75
K	10 900–36 000	2.75 – 0.834
Q	36 000–46 000	0.834– 0.652
V	46 000–56 000	0.652– 0.536

that do not detract from the ship's prime mission. These computed power densities are correlated with actual measurements subsequently obtained by survey to assure complete safety and to check the reliability of a computer ship design. Radars used for navigation, surveillance, and weapons control were the only systems surveyed initially. However, as the power outputs from other systems (such as satellite communication) became significant, they too began to be checked during surveys [8], [9], [11], [14], [15].

Commercially available test equipment is used for the surveys. Such equipment usually consists of a power meter, thermistors, calibrated antennas, attenuators, and other necessary hardware. The measurements are made using a calibrated horn antenna or dipole antenna (depending on the frequency) oriented for maximum pickup at each test location.

Measurements of the maximum power levels, which often include reflective contributions from portions of the ship structure, are considered to more accurately represent the RF environment than those limited to direct radiation from the source. When full radiated power measurements are not feasible (due to possible exposure of survey personnel to unsafe power densities), either measurements made at reduced power are extrapolated to maximum power output, or remote reading of positioned measuring equipment is utilized. The latter is useful where reflective contributions are encountered. To eliminate case penetration which may effect the measurements, power meters are placed in shielded enclosures. Considerable care is also taken to insure cable shielding integrity.

Since the ship itself is a very complicated radiating structure down to the waterline, shipboard measurements may be considered to be as much an art as a science. Reflective surfaces and secondary radiators exist in moving booms, rigging, and other rotating antennas. In the case of aircraft carriers, even the placement and movement of aircraft on the flight deck affects the power density levels.

A survey conducted on the fictitious ship U.S.S. CHARLIE BROWN, CVA (attack aircraft carrier) which closely parallels that performed on actual ships, will be described. The following radar equipment (Table II) is typical of the equipment presently in use in the fleet on ships of the class that U.S.S. CHARLIE BROWN represents.

The power output of smaller radars, such as those used for navigation, guidance in landing aircraft, and approach control (the latter two operate in the K band) have not been included in this survey since they present, in their normal operation and physical location,

TABLE III

TEST LOCATIONS USED IN THE SURVEY OF U.S.S. CHARLIE BROWN

Test Location	Test Locations[a]
1	010 level, starboard passageway
2	010 level, FR[b] 142, starboard signal bridge
3	010 level, forward passageway
4	010 level, port passageway
5	010 level near starboard primary flight control
6	flight deck, FR 105, inboard 50 ft
7	flight deck, FR 82, edge of flight deck
8	flight deck, FR 60, inboard edge of flight deck
9	flight deck, FR 82, inboard edge of flight line
27	flight deck, FR 235, inboard 75 ft
28	below flight deck, FR 224, outboard starboard catwalk
29	below flight deck, FR 218, outboard starboard catwalk
30	flight deck, FR 204, starboard crane operator position

[a] All flight deck test locations, unless otherwise indicated, are relative to the port edge and at a height of approximately 6 ft.

[b] FR denotes frame, see note Fig. 1.

TABLE IV

POWER DENSITY MEASUREMENTS, AN/SPG-99

Test Location[a]	Director Number	Antenna Orientation Az[b] (deg)	Antenna Orientation El[c] (deg)	Frequency Band	Typical Average Power (kW)	Main[d] Beam	Power Density (mW/cm²)
1	1	000	−14	X	3.0	yes	28.0
2	1	000	−14	X	3.0	yes	40.0
6	2	323	−8	X	3.0	yes	25.0
7	2	323	−8	X	3.0	yes	33.0
8	2	323	−8	X	3.0	no	41.0×10^{-2}
9	2	323	−8	X	3.0	no	20.0×10^{-2}
27	2	204	−9	X	3.0	no	10.6×10^{-2}
28	3	059	8	C	5.0	no	19.3×10^{-2}
29	3	059	8	C	5.0	no	8.6×10^{-2}
30	3	059	8	C	5.0	no	24.9×10^{-4}

[a] See Fig. 1, U.S.S. CHARLIE BROWN.

[b] Azimuth relative to bow.

[c] Elevation relative to horizon.

[d] If other than main beam, this represents a lobe or reflected energy.

very little hazard to personnel. In addition, the output of many types of transmitters, such as those used for short range communication (i.e., between the aircraft pilot and the ship, which operate in the VHF/UHF portions of the P and L bands) are not included since the present power outputs do not constitute a hazard. Aircraft containing radar transmitters are parked in such a way on the flight deck of carriers, and/or their radar antennas oriented so that the beam from their radar (when being checked and/or serviced) is directed away from personnel, ordnance, and fuel, thus further limiting the hazards.

Power density measurements for a typical survey are made at various test locations (Table III), as illustrated in Fig. 1. The measurements are usually made with the transmitters operating independently. The results are summarized in Tables IV–VII which, together with Table III, has been abbreviated, and show only a few test points.

TABLE V

POWER DENSITY MEASUREMENTS, AN/SPS-83

Test Location	Antenna Orientation Az (deg)	Antenna Orientation El (deg)	Frequency Band	Typical Average Power (kW)	Main Beam	Power Density (mW/cm²)
1	090	000	P	7.0	no	25.0×10^{-2}
2	090	000	P	7.0	no	50.0×10^{-2}
3	090	000	P	7.0	no	33.4×10^{-2}

TABLE VI

POWER DENSITY MEASUREMENTS, AN/SPS-89

Test Location	Antenna Orientation Az (deg)	Antenna Orientation El (deg)	Frequency Band	Typical Average Power (kW)	Main Beam	Power Density (mW/cm²)
2	000	25	S	2.5	no	no indication
3	000	25	S	2.5	no	no indication

TABLE VII

POWER DENSITY MEASUREMENTS, AN/SPS-70

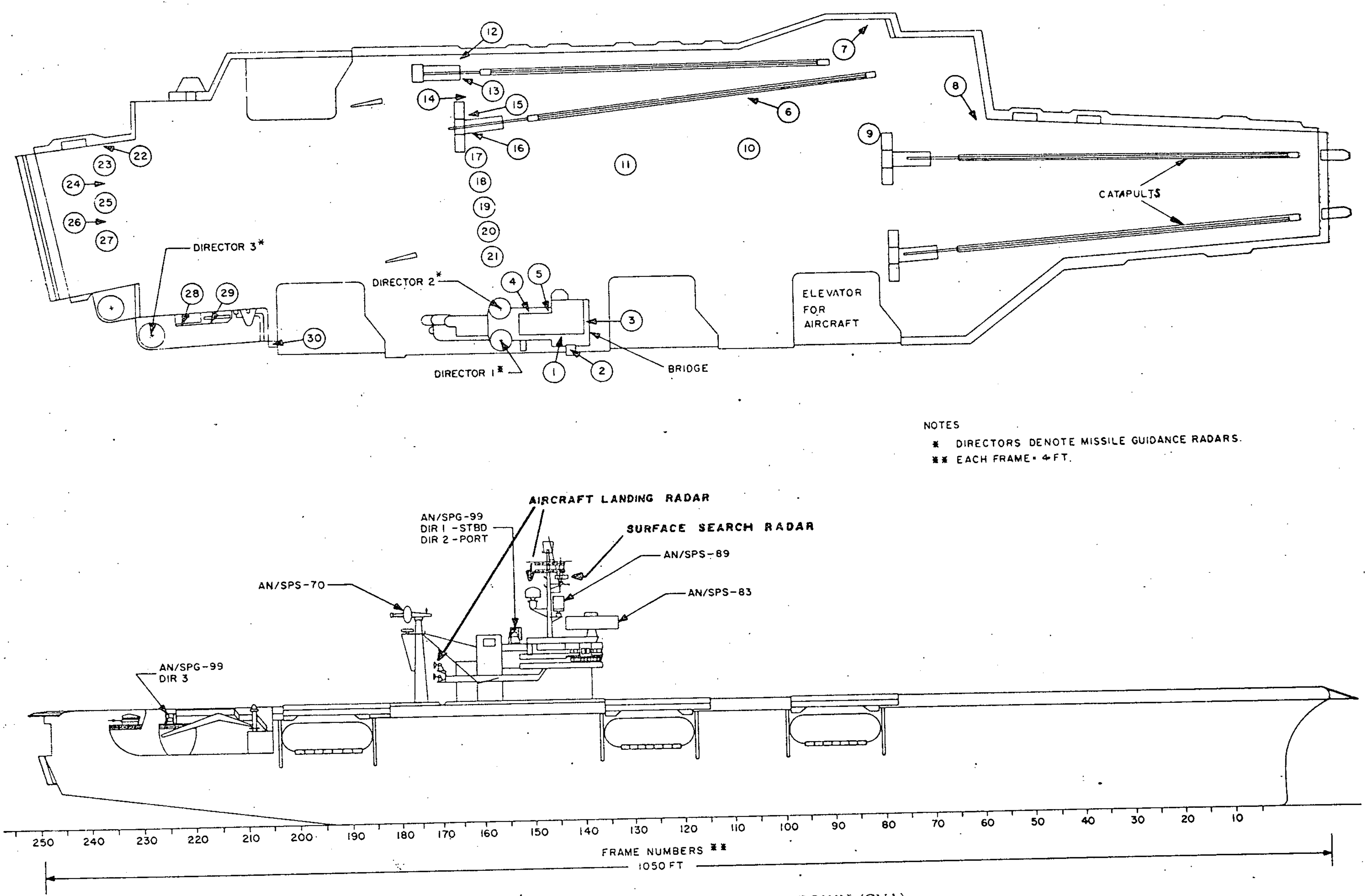
Test Location	Antenna Orientation Az (deg)	Antenna Orientation El (deg)	Frequency Band	Typical Average Power (kW)	Main Beam	Power Density (mW/cm²)	Power Density Extrapolated to Full Power (mW/cm²)
3	352	0	S	2.0	no	no indication[a]	
4	352	0	S	2.0	yes	15.9	63.6
5	352	0	S	2.0	yes	15.9	63.6

[a] Test location is shaded by obstacles and cannot be radiated by main beam.

A report based on the survey measurements is prepared to advise the commanding officer of the existence of hazardous shipboard areas, and recommends courses of remedial action to minimize the possibility of injury to personnel.

The techniques used to either eliminate or reduce RF radiation to accepted safe power density levels are the following: 1) mounting transmitting antennas above the highest manned level; 2) utilizing emission control (i.e., the use of cam cutouts to prevent equipment from radiating within the profile of the ship as seen by the antenna beam); 3) restricting or limiting access to certain spaces by posting radiation warning signs (Fig. 2) and using the ship's public address system to advise that specific weather (exposed) decks are restricted while equipment is activated; and 4) using area shielding (e.g., metallic screening) to permit occupancy of otherwise hazardous weather decks. The wearing of safety clothing (Fig. 3) and goggles (Fig. 4) has also been considered; however, neither is in general use at this time [12], [13], [18].

Relocation of a radar antenna is made only when cam cutout and/or shielding causes unacceptable operational limitations on the radar, and when personnel

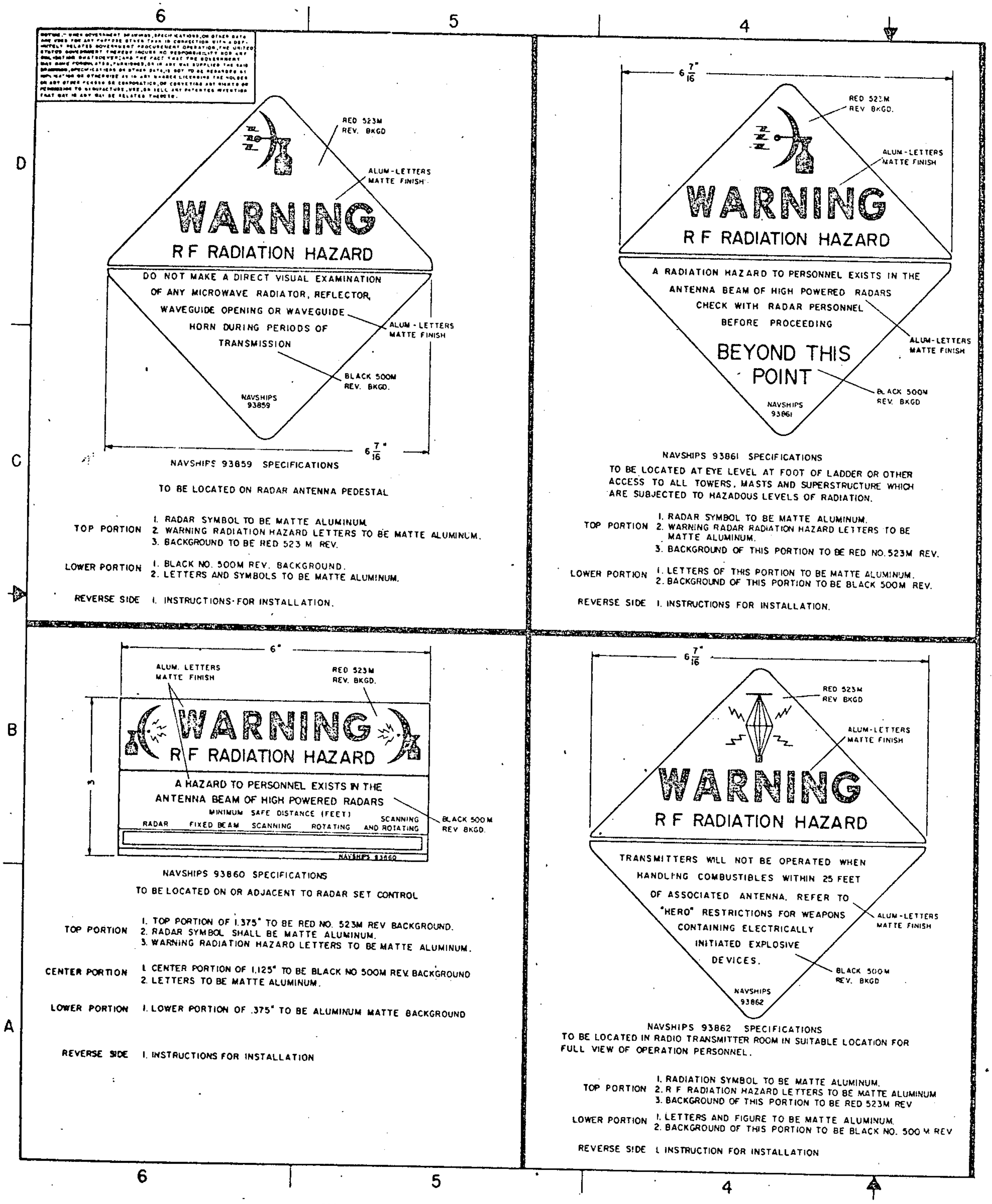


NOTES

* DIRECTORS DENOTE MISSILE GUIDANCE RADARS.

** EACH FRAME = 4 FT.

Fig. 1. Test locations, U.S.S. CHARLIE BROWN (CVA).



NAVSHIPS 93859 SPECIFICATIONS

TO BE LOCATED ON RADAR ANTENNA PEDESTAL

TOP PORTION
1. RADAR SYMBOL TO BE MATTE ALUMINUM
2. WARNING RADIATION HAZARD LETTERS TO BE MATTE ALUMINUM.
3. BACKGROUND TO BE RED 523 M REV.

LOWER PORTION
1. BLACK NO. 500M REV. BACKGROUND.
2. LETTERS AND SYMBOLS TO BE MATTE ALUMINUM.

REVERSE SIDE
1. INSTRUCTIONS FOR INSTALLATION.

NAVSHIPS 93861 SPECIFICATIONS

TO BE LOCATED AT EYE LEVEL AT FOOT OF LADDER OR OTHER ACCESS TO ALL TOWERS, MASTS AND SUPERSTRUCTURE WHICH ARE SUBJECTED TO HAZADOUS LEVELS OF RADIATION.

TOP PORTION
1. RADAR SYMBOL TO BE MATTE ALUMINUM.
2. WARNING RADAR RADIATION HAZARD LETTERS TO BE MATTE ALUMINUM.
3. BACKGROUND OF THIS PORTION TO BE RED NO. 523M REV.

LOWER PORTION
1. LETTERS OF THIS PORTION TO BE MATTE ALUMINUM.
2. BACKGROUND OF THIS PORTION TO BE BLACK 500M REV.

REVERSE SIDE
1. INSTRUCTIONS FOR INSTALLATION.

NAVSHIPS 93860 SPECIFICATIONS

TO BE LOCATED ON OR ADJACENT TO RADAR SET CONTROL

TOP PORTION
1. TOP PORTION OF 1.375" TO BE RED NO. 523M REV BACKGROUND.
2. RADAR SYMBOL SHALL BE MATTE ALUMINUM.
3. WARNING RADIATION HAZARD LETTERS TO BE MATTE ALUMINUM.

CENTER PORTION
1. CENTER PORTION OF 1.125" TO BE BLACK NO 500M REV. BACKGROUND
2. LETTERS TO BE MATTE ALUMINUM.

LOWER PORTION
1. LOWER PORTION OF .375" TO BE ALUMINUM MATTE BACKGROUND

REVERSE SIDE
1. INSTRUCTIONS FOR INSTALLATION

NAVSHIPS 93862 SPECIFICATIONS

TO BE LOCATED IN RADIO TRANSMITTER ROOM IN SUITABLE LOCATION FOR FULL VIEW OF OPERATION PERSONNEL.

TOP PORTION
1. RADIATION SYMBOL TO BE MATTE ALUMINUM.
2. R F RADIATION HAZARD LETTERS TO BE MATTE ALUMINUM
3. BACKGROUND OF THIS PORTION TO BE RED 523M REV

LOWER PORTION
1. LETTERS AND FIGURE TO BE MATTE ALUMINUM.
2. BACKGROUND OF THIS PORTION TO BE BLACK NO. 500 M REV

REVERSE SIDE
1. INSTRUCTION FOR INSTALLATION

Fig. 2. RF radiation hazard warning signs [6].

cannot be excluded from occupancy of the hazardous area. While infrequent, such circumstances have occurred.

The Navy's interest and development effort in protective clothing [7] stems from the recognition that the performance of duties will, at times, require entry or passage through hazardous topside areas when it is not possible to turn off the radar equipment. The radar protective suit made from metalized Nylon, shown in Fig. 3, shields the wearer primarily by reflecting the incident radiation. The suit requires the wearing of an overgarment (such as coveralls) to prevent arcing when worn in the presence of power levels exceeding 150 mW/cm².

The radar safety goggles (Fig. 4) were developed primarily for use in radar research; their use aboard ship is not contemplated at this time. They are similar to welders safety goggles and possess lenses either having a metallic film coating or containing a micromesh screen. The goggles are lined with commercially avail-

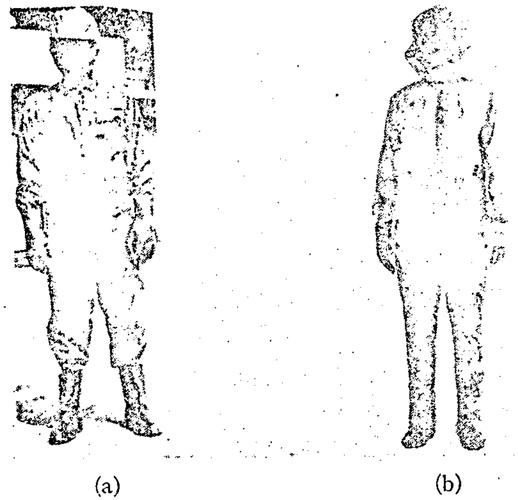

(a) (b)

Fig. 3. (a) Overgarment with fabric-protective boots and gloves. (b) Radar protective suit [9].

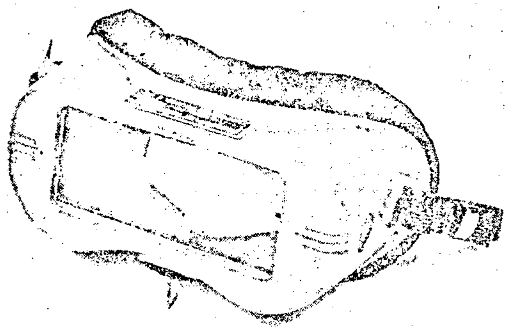


Fig. 4. Radar safety goggles [9].

able RF absorbing material, and the exterior is coated with a conductive paint designed to reflect microwave energy.

The measured power densities at test locations 1, 2, 6, and 7 (Table III) exceed the safe levels and require that appropriate measures, such as those mentioned previously, be taken. The Electromagnetic Survey Group would recommend, in this case, the use of cam-actuated azimuth- and elevation-sector radiation cutouts. Their report would also include the minimum angles required to assure the safety of the 010 level and the flight deck personnel. The home port of U.S.S. CHARLIE BROWN or an overhaul yard would fabricate, install, and optically check the recommended cam cutouts. A resurvey of locations 1, 2, 6, and 7 could then be requested following installation of the cams.

While this simulated radiation hazard survey found no other problems aboard U.S.S. CHARLIE BROWN, actual surveys of this type have confirmed the existence of hazardous shipboard areas with power levels in excess of 100 mW/cm². Naval radars capable of exceeding the safe levels by approximately two orders of magnitude (in the near field of the main beam) are now in use. Fig. 5 shows the power density as a function of distance for an actual fire control radar operating in the C band.

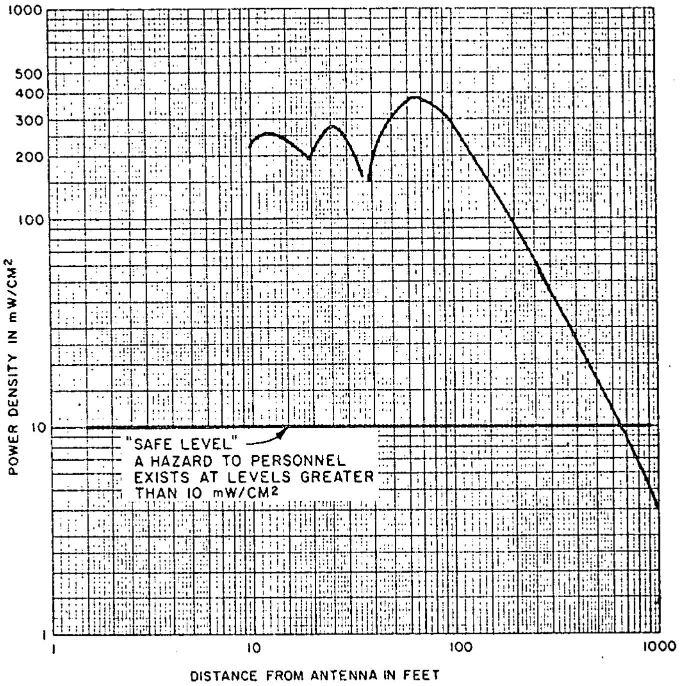


Fig. 5. On-axis power density for a missile control radar operating in the C band at 6-kW average power.

It should also be noted that the limiting radiation hazard distance (Table I) for certain radars is equal to, or in excess of, the overall length (Fig. 1) of some of our largest ships.

Certain shipboard personnel work daily in an environment where the RF power density only a few feet above their head may exceed safe levels. Some weather deck areas cannot even be entered due to the high power densities. Pilots of aircraft routinely fly through the ship's radar beams during takeoff and landing operations. Thus, it is extremely important to refine the values for maximum permissible exposure.

As pointed out earlier, much concern has been shown, by military as well as civilian research workers, regarding the reported biological effects resulting from the exposure to microwave and RF radiation. A number of suggestions have been made to modify the presently allowed maximum permissible exposure levels for man. If the levels are set too liberally, the possibility of danger to the health of personnel exists. On the other hand, if the levels are set too conservatively, undue restrictions might be imposed on the operational capability of the fleet. In addition, a number of unanswered questions exist, such as the applicability of the maximum permissible exposure level over the entire RF/microwave spectrum; the existence of specific hazardous frequencies; threshold power levels for damage; cumulative radiation effects; the hazards from multiple-source irradiation; and the hazard differences between pulsed and continuous wave irradiation, between peak versus average power levels, and between near versus far-field irradiation. For these reasons, reexamination of the existing knowledge of the biological hazards of nonionizing radiation, biomedical research to quantitate the hazards to man, and studies to provide adequate safeguards against these hazards have been undertaken by the Navy.

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