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RF RADIATION HAZARDS TO SPACE STATION PERSONNEL

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16. ABSTRACT

Although there is controversy concerning possible effects of exposure to microwave radiation, some harmful effects have been proven, such as formation of cataracts in the eyes. The proven effects alone justify precautions to insure that personnel are not exposed to harmful levels of RF radiation.

Calculation of typical values of RF power density in the vicinity of space station antennas are included in this document. More definite calculations can be made when the system configurations have been more completely defined. However, the values calculated demonstrate that the currently accepted safe limits of RF radiation can be exceeded easily in the near field of high gain antennas on the space station. Personnel working in the field of these antennas should be protected from overexposure to this radiation.

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TABLE OF CONTENTS

LIST OF TABLES

TECHNICAL MEMORANDUM X-64523

RF RADIATION HAZARDS TO SPACE STATION PERSONNEL

INTRODUCTION

There is currently much controversy and uncertainty concerning the possible effects on the human body of exposure to electromagnetic energy in the microwave frequency ranges. The maximum safe level of radiation for all-day exposure is currently accepted in the United States as 10 mW/cm^2. However, there is some pressure for the adoption of a more stringent limit on exposure levels [1].

The purpose of this document is not to argue what exposure level should be allowed or what the possible biological effects might be. The purpose is to examine the possible levels of RF radiation to which personnel on the space station and similar spacecraft might be exposed. Because of the lack of a firm design, definite calculations cannot be made at this time. However, some typical situations that might be encountered are examined for the possibility of radiation hazards. The radiation level to be allowed on the space station should be a matter of much further study.

RF EXPOSURE STANDARDS

In the United States, the currently accepted permissible level of RF radiation is 10 mW/cm^2 for continuous exposure. Higher power densities are permitted for situations in which the time of exposure is closely controlled. For power densities from 10 to 100 mW/cm^2, the allowable time of exposure is given by the formula [2]

$$T = 6000/W^2 \quad , \qquad (1)$$

where T is the allowable exposure time in minutes per hour and W is the power density expressed in mW/cm^2. Examples of allowable exposure times are given in Table 1.

TABLE 1. EXAMPLES OF ALLOWABLE EXPOSURE TIMES

Power Density (mW/cm^2)	Exposure Time (min/hr)
10	60
15	26.7
20	15
25	9.6
30	6.7
40	3.7
50	2.4

The Soviet Union enforces a much more stringent maximum of 0.01 mW/cm^2 for all-day exposure. For exposures of 15 to 20 minutes per day, a power density of 1.0 mW/cm^2 is allowed [3].

These widely differing standards have been one source of the controversy that has arisen. Another area of controversy is that of the biological effects caused by exposure to RF radiation. Some effects, however, have been conclusively proven. The excitation of atoms by microwave radiation results in the production of heat. The depth of penetration, and therefore the depth at which heating occurs, is dependent on the frequency of the radiation. At frequencies below 1000 MHz, the energy penetrates into the body, and vital organs may be heated. Above 3000 MHz, the heating is near the skin, but heat may be conducted to the deeper tissues. In the frequency band between 1000 and 3000 MHz, a combination of penetration and the skin effect may occur.

There have been some alleged cases of death resulting from exposure to very high microwave power densities. Formation of cataracts in the eyes of both experimental animals and man has been demonstrated after exposure for a few minutes. Some people hear a buzz when exposed to microwave radiation; what is heard is probably the pulse repetition frequency. A sense of warmth may be experienced by those exposed to microwave radiation, especially in the frequency range from 8 to 26 GHz. Stomach distress and nausea have occurred in cases of exposure to radar at power densities as low as 5 to 10 mW/cm^2. This effect usually is associated with the frequency range from 8 to 12 GHz. There are other, more questionable effects that may be produced by exposure to high levels of microwave radiation. Those mentioned here, however, are sufficient to demonstrate the need for protecting personnel from such exposure.

POWER DENSITY CALCULATIONS

The power density at a distance R meters from a lossless isotropic antenna is given by the formula

$$P.\ D. = P_{rad}/4\pi R^2 \qquad W/m^2 \qquad (2)$$

in which P_{rad} is the power in watts radiated from the antenna. If the antenna is not isotropic but has a directivity D , the expression for maximum power density becomes

$$P.\ D._{max} = P_{rad} D/4\pi R^2 \qquad W/m^2 \quad . \qquad (3)$$

The maximum power density would exist only in the direction of maximum radiation, which is the peak of the antenna pattern. For the general case of an antenna having both directivity and losses, the expression becomes

$$P.\ D._{max} = P_{rad} D\eta/4\pi R^2 \qquad W/m^2 \quad , \qquad (4)$$

where η is the efficiency of the antenna. Since the gain of the antenna is given by

$$G = D\eta \quad , \qquad (5)$$

the expression for maximum power density becomes

$$P.\ D._{max} = P_{rad} G/4\pi R^2 \qquad W/m^2 \quad . \qquad (6)$$

The far field of an antenna begins, by definition, at a distance R where

$$R = 2d^2/\lambda \qquad m^2 \quad . \tag{7}$$

In this expression, d is the largest linear dimension of the antenna [4] and λ is the wavelength of the radiation. Beyond this range, almost all of the power exists in a mode which is propagating outward from the antenna, so that the power density varies as $1/R^2$. At ranges in the near field, however, not all of the power exists in this outward propagating mode. Some of the power goes into other modes, such as the radial modes, so that the outward propagating or axial mode no longer varies as $1/R^2$.

Formulas and curves of axial power density for parabolic antennas are given on pages 186 and 187 of Reference 5. The axial power density at a distance $2d^2/\lambda$ meters from the parabolic antenna is given there as

$$P.\ D._{max} = 158.4 P_{kW}/d^2 \qquad mW/cm^2 \quad , \tag{8}$$

where d is the antenna diameter in feet and P_{kW} is the radiated power in kilowatts. The curve on page 187 of Reference 5 shows the axial power density variation in the near field. It can be seen that the axial power density in the near field can be as much as 41 times as great as the axial power density existing at the $2d^2/\lambda$ distance.

Using these curves and the equations that have been given, some possible radiation levels on the space station are shown in Tables 2 and 3. For low gain antennas, equation (6) has been used to calculate power density. For the high gain parabolic antennas, the equations and curves given in Reference 5 have been used.

SHIELDING FROM RF RADIATION

Various materials may be used to shield personnel from RF radiation. A thickness of 1 or 2 mils of a metal that is a good conductor will provide

TABLE 2. EXAMPLES OF LOW GAIN ANTENNA RADIATION LEVELS AT 20W POWER

	Distance from Antenna (m)	Maximum Power Density (mW/cm^2)
Case I		
0 dB antenna gain (G = 1)	1	0.159
	5	0.0064
	10	0.0016
	50	0.00006
Case II		
6 dB antenna gain (G = 4)	1	0.637
	5	0.025
	10	0.0064
	50	0.00025

very nearly total protection from direct radiation. In the frequency range from 1 to 12 GHz, 60 by 60 mesh screen will allow only about 1 percent of the incident radiation to pass. Window screening (32 by 32 mesh) will pass less than 2 percent in the same frequency range; 6.35 mm mesh will pass less than 2 percent at 1 GHz, but at 12 GHz it allows 10 percent transmission. Glass will allow 40 to 65 percent transmission depending on frequency.

When shielding from microwave energy, one should consider the possibility of reflected or refracted waves. The path of least attenuation should always be considered.

CONCLUSIONS

It can be seen that a possible RF radiation hazard exists for space station personnel exposed to the main beam of high gain antennas. The greatest hazard exists in the near field region of the high gain antennas, where power densities may easily exceed 10 mW/cm^2. The power densities calculated here are for power in the outwardly propagating mode only. In the near field of an antenna, personnel would be exposed also to the power existing in the near field modes in addition to that calculated here. Care should be taken to keep unshielded personnel out of the main beam and the near field of the high gain antennas.

TABLE 3. EXAMPLES OF HIGH GAIN PARABOLIC ANTENNA RADIATION LEVELS AT 20W POWER[a]

	Frequency (MHz)	Antenna Diameter [m (ft)]	Near Field Distance (m)	Max Axial Power Density at $2d^2/\lambda$ (mW/cm^2)	Max Axial Power Density at one-tenth of $2d^2/\lambda$ (mW/cm^2)
Case III					
20 dB antenna gain	250	5. 17 (17)	44. 1	0. 011	0. 451 at 4. 41 m
(G = 100)	1 000	1. 28 (4. 2)	10. 7	0. 18	7. 38 at 1. 07 m
	2 200	0. 58 (1. 9)	4. 87	0. 88	36. 1 at 0. 487 m
Case IV					
30 dB antenna gain	1 000	3. 96 (13)	104	0. 0188	0. 77 at 10. 4 m
(G = 1000)	2 200	1. 82 (6)	48. 7	0. 088	3. 61 at 4. 87 m
	6 000	0. 67 (2. 2)	17. 6	0. 655	26. 85 at 1. 76 m
Case V					
45 dB antenna gain	4 000	5. 78 (19)	882	0. 0088	0. 361 at 88. 2 m
(G = 32 000)	10 000	2. 28 (7. 5)	335	0. 057	2. 32 at 33. 5 m
	15 000	1. 52 (5)	228	0. 127	5. 21 at 22. 8 m

a. Power densities for transmitted powers other than 20 watts may be found by multiplying the given power densities by P/20, where P is the desired power in watts. When the beams of two or more antennas overlap, the power density should be considered as the sum of the individual power densities.

REFERENCES

1. Hardeman, Lyman J.: Microwave Oven Leakage: Federal Regulations Soon. Microwaves, February 1970, pp. 17-24.

2. Control of Hazards to Health from Microwave Radiation. Technical Bulletin No. Med 270, Air Force Manual No. 161-70, Departments of the Army and the Air Force, Washington, D. C., December 6, 1965.

3. Soviet Health Standards on Microwave Exposure. Microwaves, April 1969, p. 26.

4. Jasik, Henry: Antenna Engineering Handbook. McGraw-Hill Book Company, New York, 1961, pp. 2-13 through 2-15.

5. Hansen, R. C.: The Microwave Engineer's Handbook and Buyer's Guide. Horizon House, Dedham, Mass., 1966, pp. 186-187.

APPROVAL

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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