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REPORT
OF HEALTH HAZARDS SURVEY ON XS-AM-7 RADAR SYSTEM

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GREENBELT, MARYLAND

REPORT OF HEALTH HAZARDS SURVEY ON XS-AM-7

RADAR SYSTEM*

JUNE 10-11, 1964

Radiological Office
Goddard Space Flight Center
Greenbelt, Maryland

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I. Purpose

The purpose of the survey was to determine the radiation hazards (both r-f and x-ray) surrounding an XS-AM-7 radar system, and, based on this information, make recommendations pertaining to the potential radiation hazards of Goddard's tracking installations.

The XS-AM-7 radar system is presently used for tracking purposes. The six foot diameter antenna is located approximately ten feet off the ground with a capability of no-limit azimuth and $-10^\circ \dashrightarrow 90^\circ$ elevation. At the time of the survey no operating restrictions had been imposed and no warning signs were displayed, since the exact nature of the potential hazard was not known by the operating personnel.

II. Operating Data

The following data pertaining to the installation were taken directly from the Department of the Army Technical Manual, TM-9-5020-2, August, 1959.

A. Antenna System

Type: Metal plate, phase advance lense.
Radiating element: Monopulse type with four feed horns.

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*Survey and report were performed by Controls for Radiation, Inc., 130 Alewife Brook Parkway, Cambridge 40, Massachusetts for Goddard Space Flight Center, Greenbelt, Maryland under Contract No. NAS 5-3580.

Beam width: 21 mils between half power points.
Gain: 40 db.
Crossover loss: 1.5 db.
Polarization: Vertical.

B. Transmitter System

Frequency: X-band 8500-9600 mc tunable over 12% band.
Transmitter: Tunable magnetron.
Peak r-f power: 250 kw.
Pulse Repetition Rate: 1000 pps.
Pulse width: 0.18 microseconds.
Pulse shape: Trapezoidal.
Modulator type: Hydrogen thyratron line type.

III. Measuring Equipment

The instrument employed for the field strength measurements was a Broadband Power Density Meter, Singer Metrics Division, The Singer Company, Model NF-157. This instrument is capable of covering the frequency range from 200 megacycles to 10,000 megacycles with three different r-f pick-up probes. The power density range is from 0.1 milliwatt per square centimeter to two watts per square centimeter, with an accuracy of one db at midscale.

Instrumentation used in the x-radiation survey around the magnetron housing included direct reading pocket ionization chambers (dosimeters), Landsverk Electrometer Company, Model L-49, and Survey Meter Technical Associated, Model SRJ-1.

The dosimeters are capable of measuring the integrated dose from pulsed x-rays and are not affected by milliwatt levels of r-f radiation.[1] The dosimeters measure doses up to 250 milliroentgens.

The Juno Survey Meter is capable of measuring dose-rates from one milliroentgen/hour to five roentgens/hour. It was realized at the time of the survey that the Juno Survey Meter was not insensitive to microwave radiation.

[1] Wall, James A., Final Report Analysis of Pulsed X-Radiation Generated by High Powered Electronic Equipment, RADC-TDR-63-29, June 18, 1963, Contract No. AF-30(602)-2493, pp. 110-111.

In order to facilitate the survey procedures, portable transmitter-receivers were employed to insure rapid communication between the radar operator and survey team.

IV. Theoretical Considerations

By referring to the operating data, important and meaningful calculations can be made to evaluate the given antenna system.

The antenna system is described as a metal plate type with phase advance lense and parabolic in shape. The radiating element is monopulse type with four feed horns. Gain of the antenna is 40 db with a beam width of 21 mils or 1.2°. Polarization is vertical.

Fundamental antenna theory indicates that the r-f energy radiated by an antenna is generally complex in nature. At distances "close" to the antenna, known as the "Fresnal" or "near-field" region, the power remains fairly constant with distance. Eventually the "near-field" crosses over to the "Fraunhofer" or "far-field" region where the inverse square law variation begins to take effect. (See Figure 1a)

Using the standard circular dish antenna equations, the range of the "near-field" is determined by

$$R_{Fresnal} = <1/4 \frac{D^2}{\lambda}$$ [2]

Where

D = antenna dimension
λ = wavelength

for the XS-AM=7 system;

D = 6 feet

and

λ = 0.109

Thus, the Fresnal region extends to approximately 82.5 feet.

[2] U.S. Air Force, Handbook, Radio Frequency Radiation Hazards, T.O. 31-1-80, 15 April 1958, revised 2 January 1959, P. 2.

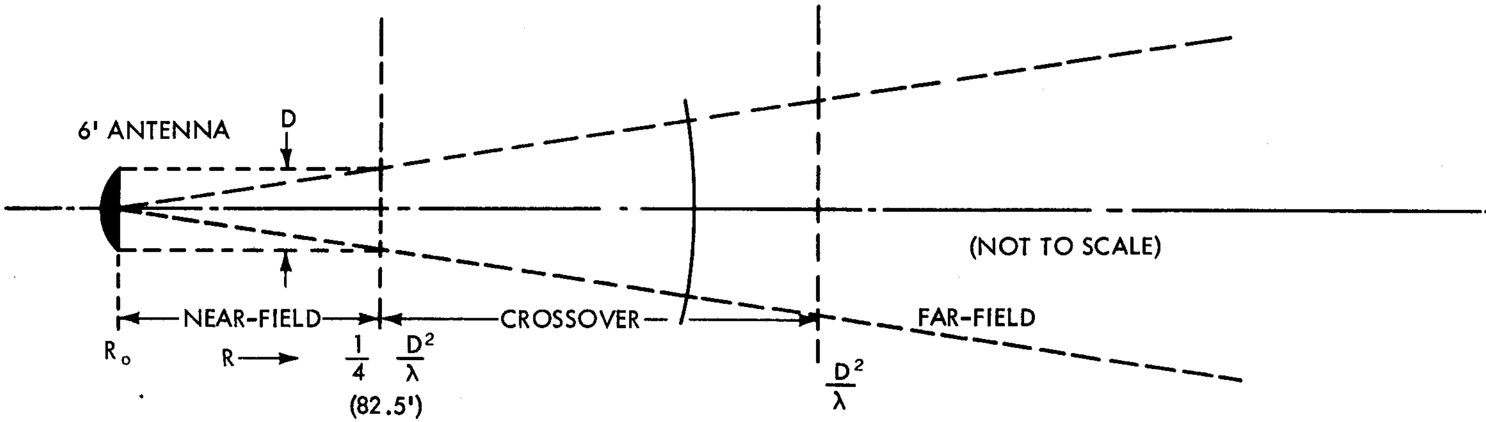

Figure 1a

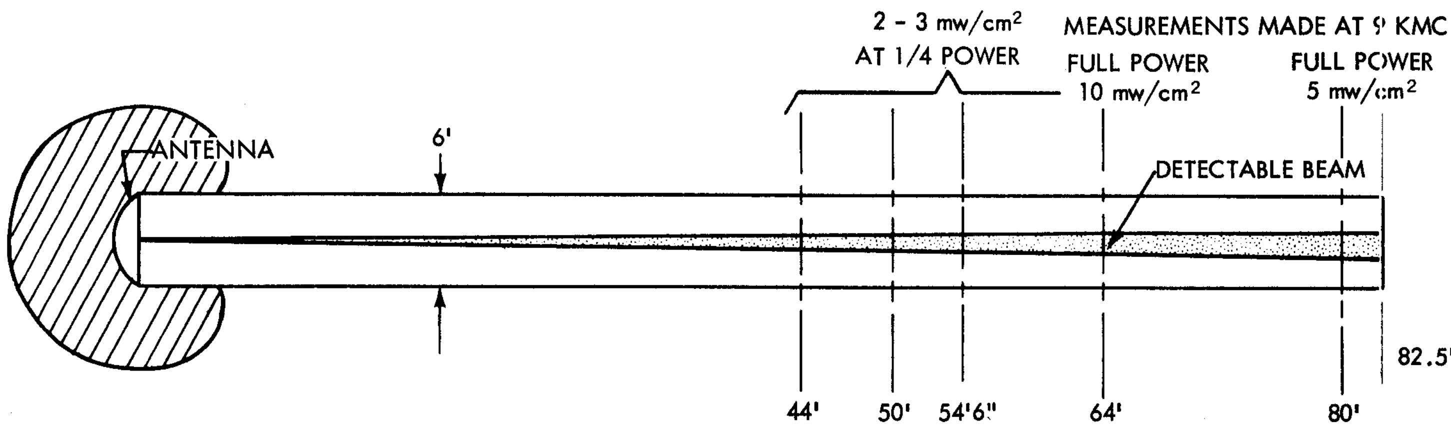

Figure 1b

From the operating data of the system, the average radiated power can easily be computed (assuming negligible loss occurs between generator and antenna).

$$P_{avg} = P_{peak} \times DC$$

where,

P_{avg} = average power
P_{peak} = peak power
DC = duty cycle defined by:
DC = PW × PRF

where,

PW = pulse width

and

PRF = pulse repetition frequency

Calculating duty cycle;

$$DC = 1.8 \times 10^{-4}$$

For average power;

$$P_{avg} = 250{,}000 \text{ watts} \times 1.8 \times 10^{-4} = 45 \text{ watts.}$$

The power density in the "near-field" region is expressed by;

$$W = 4\ P/A$$

where,

W = power density
P = Average power output

and,

A = Area of antenna.

thus:

$$W = \frac{4 \times 45 \text{ watts}}{(8100 \text{ cm}^2)} = 7.07 \text{ mw/cm}^2$$

For a properly focussed antenna, this equation gives the maximum power density, in free space, that can exist on the axis of the beam.(3) However, this calculation should be qualified, since a de-focussed antenna and ground reflections can substantially increase the power density. A 100% ground reflection doubles the electric field strength, thus quadrupling the power density.

The "near-field" beam is independent of distance, but because of an optical phenomenon, "Fresnal diffraction," the "near-field" cannot be evaluated simply as the quotient of the transmitted power by the area of the antenna aperture. In reality, the "Fresnal" region is characterized by many peaks and valleys in the power density contour. The maximum peaks always occur on the axis of the beam. The maxima is theoretically four times the quotient of the power by the antenna area.(4)

Since the system radiated with high directivity, and was vertically polarized, no hazardous r-f was expected at the rear or at the sides of the antenna.

Where any high powered electronic equipment is involved, an x-radiation hazard may possibly be present. In any electronic device where electrons are accelerated by an electric potential and de-accelerated upon collision with matter, bremsstrahlung is generated.

In this particular radar system, a magnetron generated power at potentials up to 35 kilovolts. Although it appeared to be adequately shielded, the necessary survey for x-radiation was made.

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(3)Engelbrecht and Mumford, "Some Engineering Aspects of Microwave Radiation Hazards," *Proceedings of the Fourth Annual Tri-Service Conference on the Biological Effects of Microwave Radiation,* Plenum Press, New York, 1961, p. 56.

(4)Overman, H. S., "Quick Formulas for Radar Safe Distance," *Proceedings of the Fourth Annual Tri-Service Conference on the Biological Effects of Microwave Radiation,* Plenum Press, New York, 1961, p. 50.

V. Procedures

Measurements were taken in the calculated "near-field" region to determine the power densities present.

The antenna was directed to a point 80 feet away and four feet above the ground. Two sections of string were attached to the antenna and connected to two posts six feet apart at the eighty-foot point. This arrangement provided a guide line for the r-f field measurements. (See Figure 1b).

The first set of data was taken at full power. The power density meter was adjusted to 9000 megacycles. The radar set's frequency was adjusted to give a maximum reading on the power density meter to obtain frequency continuity between transmitter and power density meter.

Measurements were taken at 80 feet and at 64 feet. Power densities of 5 and 10 milliwatts per square centimeter were detected at these points respectively.

At this point it was decided that further measurements (closer to the antenna) should be taken at a decreased power level, since the currently recommended maximum permissible limit is 10 mw/cm^2. This level is applied as a ceiling without regard to frequency of the transmitter of duration of exposure.

Since the radar set instrumentation was not capable of measuring the exact power, the approximate power change, was determined by measuring the change in power density at a given point. Then further measurements were taken at one-quarter full power.

Measurements also were taken around the antenna itself. (See Figure 1b). The back of the antenna was checked in addition to any hazardous side lobes.

For the x-radiation measurements four Landsverk dosimeters were attached to the magnetron housing for several hours of operation. The Juno Survey Meter was much too sensitive to r-f radiation to offer any x-ray data.

VI. Results

Referring to Table I the data indicated that a potential r-f radiation hazard existed within the near field region of the antenna. In addition, it was found that the r-f radiation field was a highly collimated beam. Except for the beam on the axis in Figure 1b, no r-f radiation was detected with the broad band power density meter.

At 80 feet the r-f beam appeared to be confined to an area of approximately 1.0 foot square and directly down the perpendicular axis of the antenna. At 64 feet from the antenna the detectable beam size appeared to be proportionally smaller. The beam size continued to decrease in this manner as the antenna was approached. However, as indicated by measurement #2 in Table I, the power density apparently remained constant from 72 feet to 44 feet.

Measurements taken around the antenna (side lobes) showed that no significant r-f radiation was present. The power density meter indicated no r-f radiation, but the Juno Survey Meter indicated that some form of r-f electromagnetic radiation, perhaps r-f or simply pulsed transients from the line, was present to some degree.

Table I

MEASUREMENT #1			
Frequency	Power	Distance	Power Density
9.0 KMC	full	80'	5 mw/cm^2
9.0 KMC	full	64'	10 mw/cm^2

MEASUREMENT #2			
Frequency	Power	Distance	Power Density
9.0 KMC	quarter	80'	~1 - 2 mw/cm^2
9.0 KMC	quarter	72'	~2 - 3
9.0 KMC	quarter	64'	~2 - 3
9.0 KMC	quarter	54'6"	~2 - 3
9.0 KMC	quarter	50'	~2 - 3
9.0 KMC	quarter	44'	~2 - 3

VII. Discussion of Results

Measurement #1 was taken at full power until 10 mw/cm^2 was detected. This relatively high measurement may be partially due to some reflection or it may indeed be a true "free-space" reading. At the time the measurements were made, time and equipment were limited, and measurements had to be made within a man's reach. For accurate theoretical comparisons, this was probably not the optimum procedure. However, since the purpose of the survey was to establish whether or not a health hazard existed, not an antenna pattern analysis, this method yielded realistic information regardless of possible reflections.

Measurement #2 in Table I was taken at approximately one-quarter power. The main purpose of the one-quarter power measurement was to verify the theoretical characteristics of the "near-field" region, over which the validity of the full power measurements could be established.

Although the data in measurement #2 is quantitatively inaccurate (due to low scale readings, severe zero drift, and quarter power approximation), the errors are relatively consistent from point to point. The power density levels along the axis of the Fresnal region are fairly constant, and show good agreement with r-f theory discussed in Section IV. This leads to the conclusion that the true full power reading of measurement #1 can be applied validly over the distances listed in measurement #2.

This conclusion confirms that power densities of up to 10 mw/cm^2 or more were present in the "near-field" zone of the antenna system.

Referring to Figure 2, the general lay-out of the site shows three buildings in the near vicinity of the antenna. All of these buildings are within the antenna's scanning capability, thus increasing the possibility of reflections which can quadruple the power densities up to 30 or 40 mw/cm^2. In addition, a road situated by the antenna site, approximately 100 feet away, may prove to be a hazardous area when ground reflections are incurred.

The equipment vans (See Figure 2) are well within the hazardous zone and are occupied when the antenna is operating. However, the van walls provided more than adequate r-f shielding, except for the window apertures facing the antenna.

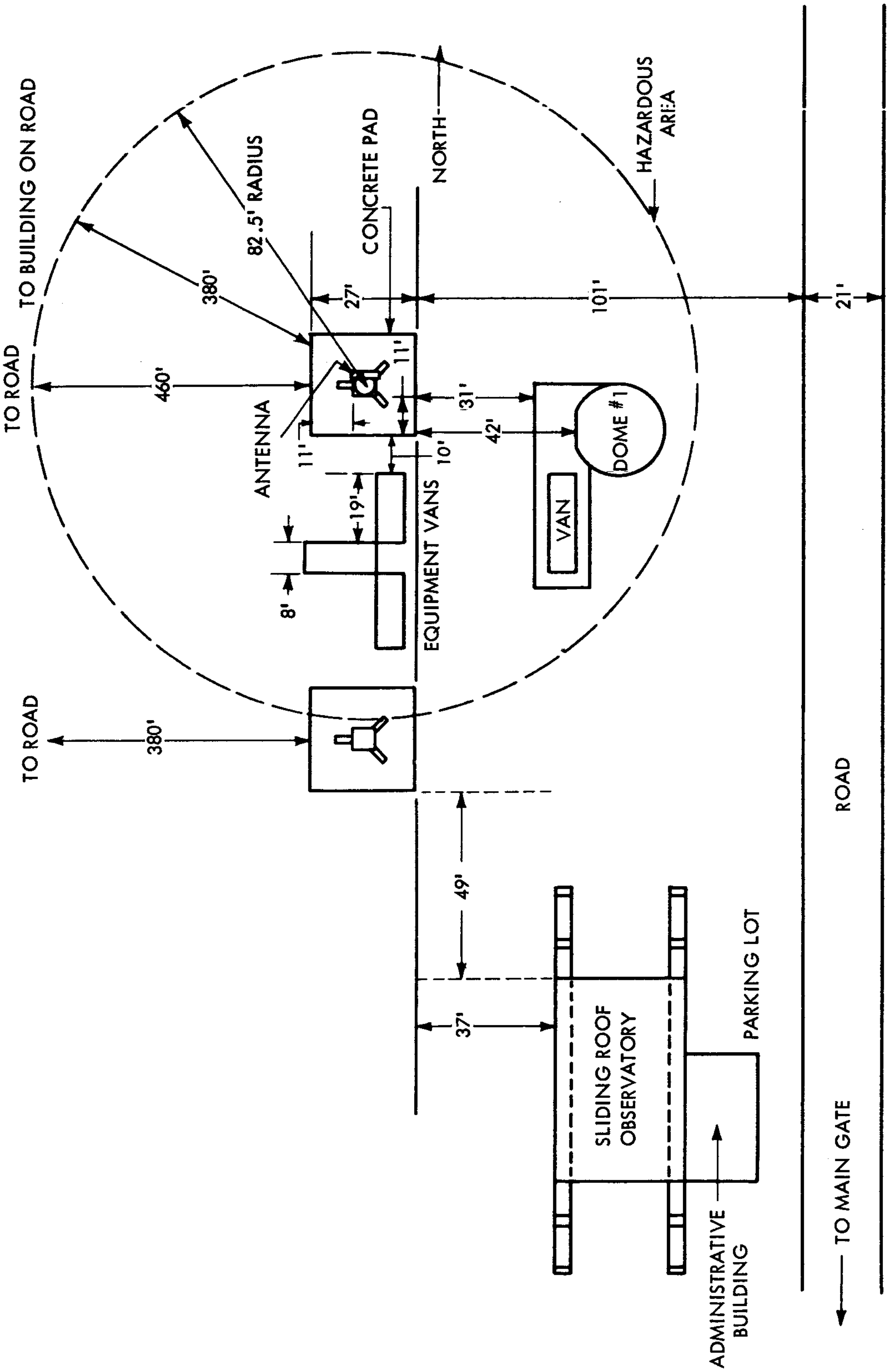
TO ROAD
380'
TO ROAD
460'
TO BUILDING ON ROAD
380'
82.5' RADIUS
CONCRETE PAD
NORTH
HAZARDOUS AREA
27'
101'
21'
11'
ANTENNA
11'
31'
42'
10'
DOME #1
VAN
19'
8'
EQUIPMENT VANS
49'
37'
SLIDING ROOF OBSERVATORY
PARKING LOT
ADMINISTRATIVE BUILDING
ROAD
TO MAIN GATE

Figure 2

Table II summarizes the x-radiation data. The Landsverk dosimeter did not indicate the presence of hazardous x-ray around the magnetron housing. Since the generated bremsstrahlung was relatively soft, little shielding was necessary to attenuate the radiation to essentially zero.

Table II

Dosimeter	Exposure	Reading
1	~3 hours	0.0
2	~3 hours	0.0
3	~3 hours	0.0
4	~3 hours	0.0

VIII. Specific Recommendations for Surveyed Installation

The above information indicates that an r-f hazard does exist around this system.

The measurement of 10 mw/cm^2 in conjunction with the possibilities of reflections indicates that proper steps should be taken to prevent unnecessary exposures.

(1) The area surrounding the antenna should be fenced to encompass a minimum radius of 82.5 feet from the antenna, and warning signs should be attached at reasonable intervals to warn of possible r-f radiation fields (see Figure 2), or

(2) The antenna should be equipped with an interlock to prevent operation at an elevation of less than +10°.

(3) Precautions should be taken against personnel exposures in the equipment vans (through the window apertures) either by means of shielding or antenna interlocks. In addition, during r-f operation precautions should be taken against accidental exposure to personnel entering or leaving the equipment vans. This can best be accomplished by instituting safety interlocks.

IX. General Recommendations for GSFC Installations

On the basis of the results of this particular survey, important conclusions can be drawn. It is evident that potential health hazards may exist around other tracking stations. It is therefore recommended that:

(1) A preliminary study be undertaken to examine and evaluate the various tracking stations presently in operation. This would be accomplished by gathering and studying the pertinent data for each station. These data should include power levels, antenna types and size, beam width, pulse repetition rate, pulse width, gain, frequencies, high power equipment specifications, and geographical lay-out of the installation in question.

(2) On the basis of theoretical calculations as were performed in Section IV of this report, determine the possible hazards of each particular station. (Most stations are probably so situated and operating at relatively low power levels, that they could be considered safe without performing an actual survey).

(3) For those installations which indicate a possible hazard, institute an on-the-site survey to determine and correct the potential health hazard. Detailed survey procedures should be outlined and a study of all available r-f detecting instruments should be undertaken.