Naval Command,
Control and Ocean
Surveillance Center RDT&E Division San Diego, CA
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Technical Report 1617
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San Diego, California 92152–5001

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ADMINISTRATIVE INFORMATION

The work detailed in this report was a cooperative effort of personnel from the U.S. Naval Command, Control and Ocean Surveillance Center (NCCOSC), Research, Development, Test and Evaluation Division, the U.S. Naval Aerospace Medical Research Laboratory (NAMRL), the Australian Defence Force (ADF), and the Royal Australian Navy. Sponsorship was provided by the Space and Naval Warfare Systems Command under program element 0101402N, accession number DN587548.

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OBJECTIVE

At the request of the Royal Australian Navy (RAN), the Naval Computer and Telecommunications Command (CNCTC) asked for a survey of current operational and maintenance procedures be done to analyze the potential for hazardous electromagnetic radiation to personnel (HERP) at the Harold E Holt (HEH) facility. Radiation Hazard (RADHAZ) measurements were made at the very-low-frequency (VLF) HEH transmitting facility by personnel from U.S. Naval Command Control and Ocean Surveillance Center (NCCOSC), Research Development Test and Evaluation Division (RDT&E Div.)[1], the U.S. Naval Aerospace Medical Research Laboratory (NAMRL), the Australian Defence Force (ADF), and RAN. The measurements were made to determine if hazardous levels of electromagnetic fields existed in locations normally accessed by personnel. NAMRL and ADF personnel were primarily responsible for the measurements on the ground and in and around the transmitter building; NRaD personnel were primarily responsible for measurements on the towers.

All parties agreed to use the newly approved IEEE Standard C95.1 (1991) for the definition of hazardous field levels. According to this standard, at VLF, hazardous fields exceed 614 V/m and 163 A/m rms (averaged over a 5-minute period). The standard allows these limits to be exceeded when it is shown that the body's current density limit is not exceeded.[2]

The HEH VLF antenna, although normally operated with all six panels active, can also be operated with only five or four active panels. Panels can be deactivated in one of two ways: (1) A panel can be electrically disconnected, taken down, and laid on the ground (one panel at a time) or (2) a panel can be left in an elevated position but electrically disconnected and grounded. This is called the hybrid mode. A tower that has only deactivated panels attached to it is said to be isolated.

RESULTS

Listed below are the antenna configurations that were tested and for which data are available. Measurements were made at locations on one inner tower and one outer tower for all configurations listed.

6 panel (normal)	max power (1.6 MW radiated)
5 panel (1 down)	full power (1 MW radiated)
5 panel (1 hybrid)	full power
4 panel (1 down, 1 hybrid)	full power
4 panel (2 hybrid)	full power

Measurements on the towers show that all locations inside any tower (except T0—the center tower) can be accessed safely for all cases.

1. NCCOSC RDT&E Div. is referred to as NRaD.

2. For frequencies between 3 and 100 kHz in a controlled area, the above field limits can be exceeded if the peak rms current density averaged over 1–cm^2 area of tissue and 1 second does not exceed 35*f ma/cm^2 where f is frequency in MHz. For uncontrolled areas, the current density limit is 15.7*f ma/cm^2.

Measurements show that, at full power, an isolated tower may be accessed anywhere on the tower, including the tower top area, without hazard from electromagnetic field levels.

Measurements on the auxiliary winch and cables used to hoist equipment up the tower indicate that the rigging can be safely installed and operated on any isolated tower while the transmitter is operating at full power. Normal grounding and bonding procedures must be taken to keep currents from making and breaking contact across loose connections such as shackles and, in particular, between the cage and the trolley line pulley.

NRaD assisted in some of the measurements in and around the transmitter building. Three areas had potential problems: (1) Extremely hazardous currents (60 A) can occur in the inactive helix house capacitor room if a connection is made between the capacitors and the floor grating; (2) High field levels exist at the unscreened windows of the power amplifiers (PAs). Operators periodically come in close proximity to these windows to visually check the PAs; and (3) Body currents in excess of the standard were observed when touching an ungrounded crane when the crane was parked under an active feeder, or used at an outer tower for disconnection of the insulator string from a lowered panel.

RECOMMENDATIONS

1. The inactive helix house capacitor room should be made off limits while the transmitter is operating. This area can be viewed and inspected from the open door but should not be entered while the transmitter is operating.

2. The PA windows should be screened because the transmitter operators place their eyes directly in the high field.

3. Personnel should not be allowed to come in contact with an ungrounded crane. For most operations, including parking, this problem can be eliminated by lowering the outriggers. For operations when the crane needs to move, the outriggers cannot be lowered, and personnel, who might touch the crane or anything connected to the crane, should wear rubber soled shoes or boots and dry gloves.

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INTRODUCTION

The U.S. Navy VLF transmitting station HEH located at the North West Cape in western Australia is being operated by RAN. This site normally operates at a radiated power level of 1-million watts and, at times, as high as 1.8-million watts radiated. This high power causes significant levels of electromagnetic fields to exist in the vicinity of the antenna and transmitter.

About 1977, while the station was under U.S. control, it was discovered that the vertical bearings on the halyard sheaves at the tower tops had frozen and needed to be repaired. The required maintenance was estimated to take nine months of downtime, which the U.S. Navy found to be unacceptable. In 1978 and 1979, Naval Ocean Systems Center (NOSC)[3] personnel visited the site to try and work out procedures that would reduce the downtime required for this maintenance.

At that time, with no set standards for exposure in the VLF frequency range, we concluded that reducing the fields to the point that no significant shock hazard existed would make it safe for work. Procedures were worked out that would reduce the fields; eliminate the shock hazard at the work area on the towers; allow the riggers to work on all towers except T0 while transmitting; and allow for rigging and for using a winch to hoist equipment up the towers. Since this original survey, several relevant things have happened: (1) The U.S. has accepted a new standard for exposure to electromagnetic radiation; (2) HEH has changed to a new frequency, 19.8 kHz; and (3) the station has obtained a new winch and changed the technique for rigging the winch that carries equipment up the tower.

Since then, awareness has increased of possible hazards to personnel from electromagnetic radiation. Several different U.S. and RAN agencies conducted HERP surveys at HEH. Conclusions of these surveys conflicted with each other primarily due to the use of different standards. Since RAN has taken over operation of the station, technical assistance has been requested to clear up the differences between the various HERP surveys, and revalidate the procedures for working on the towers while transmitting. In addition, the recent change of transmitting frequency from 22.3 kHz to 19.8 kHz has precipitated concern among station personnel regarding the safety of working on the towers.

ANTENNA DESCRIPTION

The VLF antenna at HEH has been named a TRIDECO type of antenna (HNCD, 1963, 1967). It is an electrically short top-loaded monopole as are all the U.S. Navy's VLF antennas. The top-load of the HEH antenna is made up of six diamond-shaped panels. These panels are formed by eight wires that run out from the antenna center and one catenary wire for support (figure 1). An overall top view of the antenna is given in figure 2. Note that the panels are labeled A through F when viewed clockwise from above.

3. Currently renamed NCCOSC RDT&E Div (NRaD).

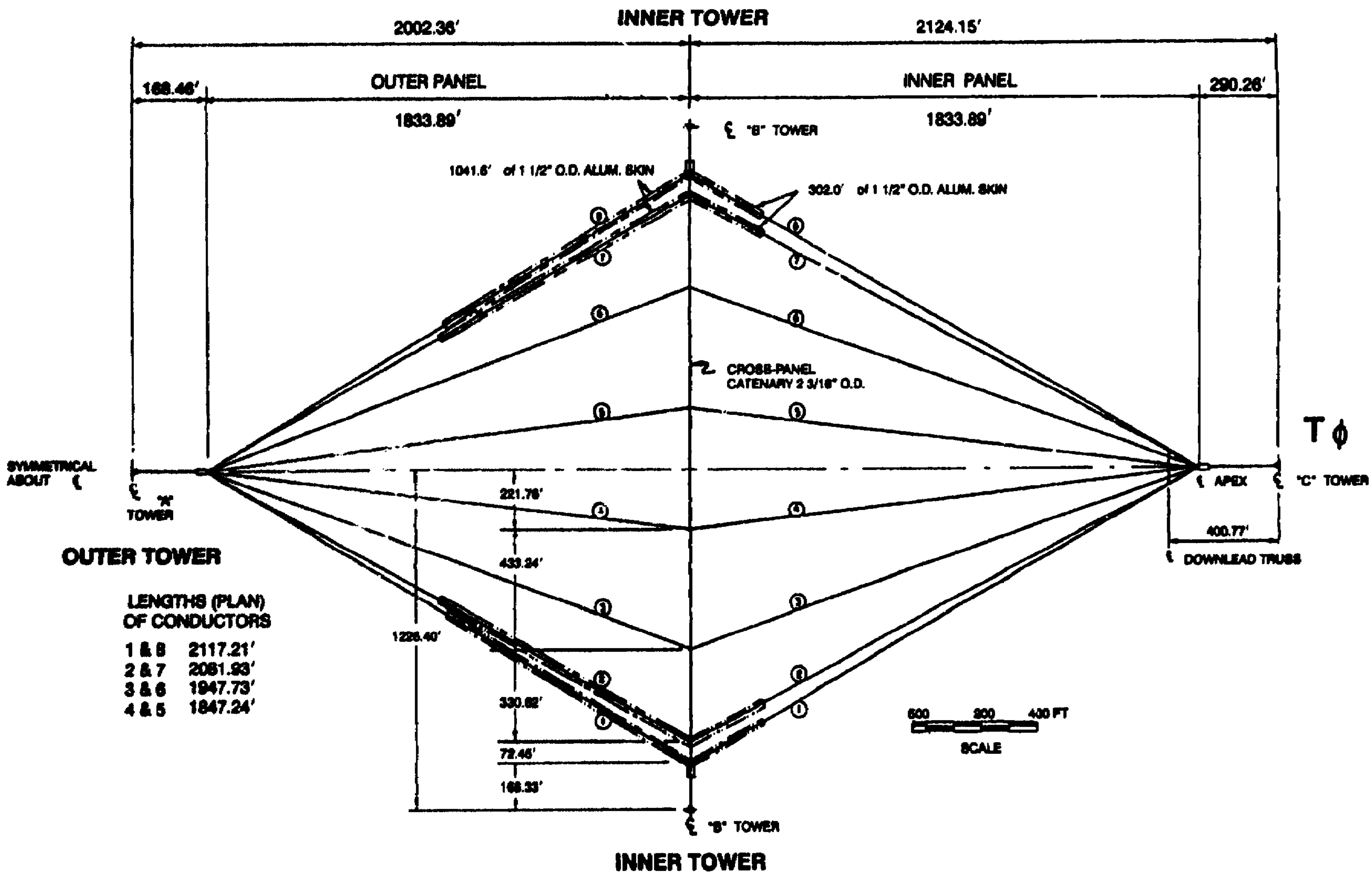


Figure 1. Plan view of typical panel.

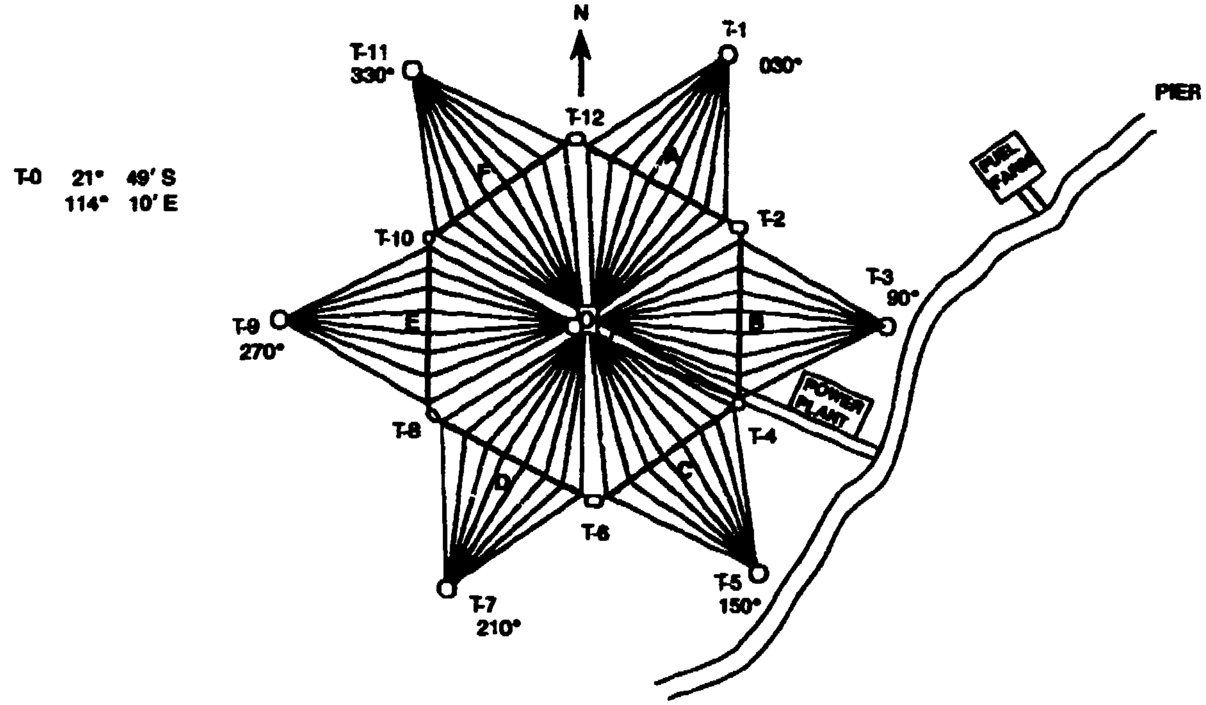


Figure 2. Top view of VLF HEH.

The 6 panels are supported by 13 towers. The towers are positioned with one tower in the center known as T0. There are six odd-numbered towers (T1–T11) located on an outer ring with radius 4126 ft. There are six more even numbered towers (T2–T12) located on an inner ring centered on T0 with radius 2124 ft. T0 is 1271 ft tall, the towers on the inner ring are 1175 ft tall, and the towers on the outer ring are 996 ft tall.

The outer apex of panel A is supported by the halyard from tower T1. The center catenary of panel A is supported between T12 and T2. The feeders are labeled with letter of the corresponding panel.

The towers, also numbered clockwise, are all grounded and supported with grounded guy wires. The top-load panels are hoisted into position by 4-part halyards attached to permanent winches at the tower base. The halyards are insulated from the panel by a string of eight Lapp compression cone insulators located at the panel corners.

The transmitter and antenna tuning system are located in a building built around the base of T0. The antenna current exits this building through two feed-through bushings on the roof. The antenna current then flows in three insulated 4-wire cages, called the feed bus system, to the pulloff insulator structures located at three points on the edge of the roof.

From each pulloff structure, two 4-wire cages, called feeders, go out towards each of two panels. The 4-wire cage feeders are suspended between the roof pulloff structure and the counter weighted down lead hinge. From this hinge, the down lead goes up to the panel. The down lead consists of an 8-wire fan suspended from a triangular truss located in the top-load panel near the panel apex. The hinge is kept in position by an insulated line connected to a counterweight (figure 3). The combination of the nearly horizontal feeder cage and the vertical fan connected at the counterweighted hinge allows the top-load panel to move over large displacements without significantly increasing the mechanical load on the feeder cage or the fan.

The structure was designed to allow lowering the panels to perform maintenance. When a panel is lowered, the 4-wire cage is disconnected from the down lead hinge. The hinge is towed out away from T0 as the panel is lowered to the ground.

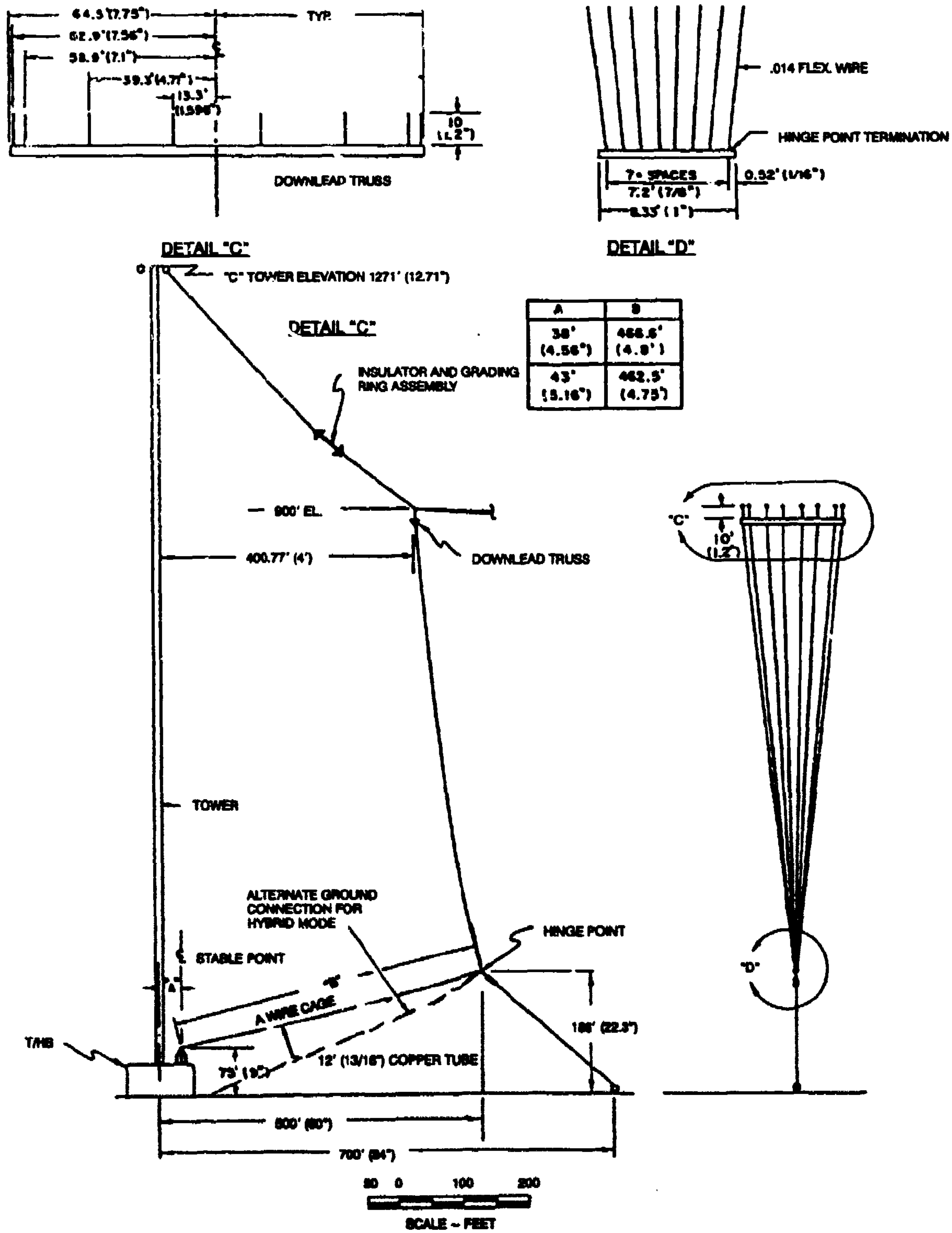
Standard practice at HEH is to set the antenna conductors on steel barrels to reduce corrosion effects on the aluminum conductors. When a panel is lowered, about 2800 barrels are put in place to accommodate the panel. Approximately 1/2 day is needed to raise or lower a panel provided that the preparation work (placing the barrels, etc.) has already been completed.

The antenna was designed to be operated with one panel lowered. However, in this condition, the antenna capacitance is reduced. This means that (1) the antenna must be retuned, (2) the antenna voltages are increased, (3) the antenna bandwidth is reduced, and (4) antenna efficiency is reduced very slightly.

During a series of trips to HEH in 1978, NOSC and HEH personnel worked out a method for working on inner and outer towers by using winches to hoist equipment while the antenna was operating. At that time, the operating frequency was 22.3 kHz. We found that it was safe to work on an inner or outer tower, if that tower was "isolated," which meant that the attached panel(s) were deactivated. One method of deactivation was to lower the panel. However, it was not practical to lower both panels connected to an inner tower because HEH did not have enough barrels. Thus, we developed a hybrid mode where the panel remained in the air but was deactivated by being grounded. This was done by disconnecting the 4-wire cage from the roof pulloff insulator structure and connecting it to anchors located near the transmitter building. Later, HEH personnel worked out a system by using a different cable to ground the panel instead of the 4-wire cage. This method for grounding an elevated panel is called the hybrid mode (figure 3).

Only one panel is connected to an outer tower. The tower can be isolated by operating that panel in the hybrid mode or by lowering that panel. Two panels are connected to an inner tower. This tower can be isolated by operating both panels in hybrid mode, or by lowering one panel and operating the other in hybrid mode.

During the 1978 and 1979 tests, no HERP guidelines existed. However, based on the concept of elimination nuisance shock, we determined that it was safe to work anywhere on an isolated tower, including outside the tower and on the top of the tower, and that it was safe to install and operate a separate winch for hauling equipment up the tower. The main concern was that arcing could damage hoist cables and possibly cause an accident. At that time, we determined that the winch and tag line cables should run in a complete loop (i.e., with no insulator in either cable). For this configuration, the maximum current in the cables was less than 8 A, which is far below the fusing current for a single outer strand and, therefore, not a problem.



NOTE: EQIVALENT FULL-SCALE DIMENSIONS SHOWN WITH MODEL DIMENSIONS IN PARENTHESIS

Figure 3. Antenna downlead details.

PARTICIPANTS

In order to prevent misunderstandings, RAN requested that teams of experts from both the U.S. and Australia participate in a joint effort. This effort took place during April 1993. The Australian team was led by Mr. John Rowell of ADF Naval Support Command; the team from NAMRL was led by Dr. Richard Olsen; and the team from NRaD was led by Dr. Peder Hansen. The three teams worked together with the ADF and NAMRL teams primarily responsible for the ground measurements and the NRaD team primarily responsible for the tower measurements.

During the course of the effort, several meetings were held by the teams and by representatives from the RAN, USN station personnel, and the Australian contractor (ADI), now responsible for running and maintaining the station. Following the kickoff meeting, and prior to starting the measurements, the teams made comparison measurements in and around the transmitter building to be sure that the instrument readings agreed.

PREVIOUS SURVEYS

This survey is the latest in a series to examine the safety of working on the HEH antenna system. The first survey was done in 1978 and 1979 by personnel from the station, NOSC, and Boynton Hagaman of Kershner and Wright (Hagaman, 1978, 1979). At that time, no standard existed to guide station personnel in the proper procedures to work in a high-field environment. This survey team developed procedures to safeguard personnel from any accidental injury caused by high-field levels.

A second survey was undertaken in October 1989 by a joint U.S. and Australian team consisting of personnel from the Naval Electronic Systems Engineering Center (NAVELEXCEN) Charleston and ADF. These two teams used similar measuring instruments and measured virtually the same field levels. However, the two teams were operating under different standards for maximum permissible exposure (MPE) limits (Charlow, 1990; Joyner, 1989, 1991).

At the time of the survey, the U.S. team was operating under USN OPNAVNOTE 5100 which set MPE at the following limits:

E-field:	632 V/m
H-field:	1.6 A/m

The applicable Standard Association of Australian (SAOA) standard at that time, AS 2772 – 1995 (SAOA 1985) had no MPE limits at VLF. Therefore, the ADF team used the International Radiation Protection Association (IRPA) standard (IRPA 1988) to set the MPE limits for their survey. Although the IRPA standard does not extend below 100 kHz, it does allow a limit to be set if compelling practical reasons exist. The applicable limits at the October 1989 frequency of 22.3 kHz were as follows:

E-field:	614 V/m
H-field:	73 A/m
Induced currents:	1000*f (f in MHz) through each foot. Ie 22.3 mA at the HEH operating frequency.

The recommendations made by both teams for reducing hazardous field exposure were virtually identical. These recommendations included screening the viewing windows and helix house switch room staircases, and not allowing personnel to work outside the towers when doing maintenance. Both survey teams, however, stipulated that their recommendations would be different under the then proposed American National Standards Institute (ANSI) standard C95.1–1990, which has a higher magnetic field limit (162 A/m).

Subsequent to this survey and at the request of CNCTC, in October 1990, personnel from the Bureau of Medicine and Surgery (BUMED) and NAMRL conducted a RADHAZ survey to reevaluate the previous survey. BUMED contended that current research demonstrated that personnel hazard at VLF is only dependent on current density induced in the body. Thus, the actual limiting factor in defining personnel hazards when either the E- or H-field limits from OPNAVNOTE 5100 were exceeded is given by the following body current limits:

Frequency Range (MHz)	Through Both Feet	Through Each Foot or Contact
0.003 – 0.1	(900 mA) x (f)	(450 mA) x (f)
0.1 – 1.0	90 mA	45 mA

(f is frequency in MHz)

The BUMED/NAMRL team concluded that no personnel hazard existed inside or outside the transmitter building. Their measurements showed no significant body current induced in personnel while inside the transmitter building, and body currents of less than 5 mA while personnel were outside of the transmitter building. These values are well within the body current standard of about 20 mA for an operating frequency of 22.3 KHz (BUMED, 1991).

In June 1991, NAMRL conducted a subsequent survey at the request of BUMED when the operating frequency was changed to 19.8 KHz (Olsen, 1992). By this time, a definitive standard had been published by the Institute of Electrical and Electronic Engineers (IEEE, 1991). The MPE limits are identical to those of the proposed ANSI standard.

The measurements were not confined to a 6-panel case for the NAMRL survey. Measurements for the 5-panel and 4-panel cases were also taken because personnel work under the antenna and in and around the towers while operating in these configurations. NAMRL's June 1991 results at 19.8 kHz did not differ substantially from those of the October 1990 survey. However, they did recommend that caution be exercised in allowing personnel to remain outdoors in the immediate vicinity of the transmitter building during 5-panel and 4-panel operation. NAMRL also recommended that proper grounding be used when cranes are in use and when the feedpoint apex to a panel is lowered.

STANDARD USED

The VLF RADHAZ exposure standard IEEE C95.1–1991 was chosen for the 1993 survey by the NAMRL, ADF, and NRaD teams.

The MPE limits in this standard for controlled areas are as follows:

E-field:	614 V/m
H-field:	163 A/m
Induced currents:	1000*f (f in MHz) through each foot.
	Ie 19.8 mA at the HEH operating frequency.

The standard allows the relaxation of the field limits in controlled environments as long as it can be shown that the peak rms body current density does not exceed 35*f mA/cm, averaged over any 1 cm^2 area and 1 second, where f is frequency in MHz. We agreed at a kickoff meeting that this maximum current density corresponds to the current limits through a hand or foot given in the above list. Simply stated, for controlled areas, IEEE C95.1–1991 allows the electric field limit of 614 volts/m to be exceeded as long as we have shown by measurement that the induced currents through a wrist and/or ankle are less than 19.8 mA.

EXPECTED FIELDS

ELECTRIC FIELDS

The coarse estimates of the expected fields derived from voltages and currents and the antenna dimensions are detailed in appendix A. The estimated average electric field (Eavg) under the top-load is given in the table 1, as is the maximum electric field (Ef) under the feeders.

Table 1. Estimated electric fields for operating modes at VLF HEH 19.8 kHz.

	6 Panel	5 Panel	4 Panel
Eavg (v/m)	678	617	734
Ef (V/m)	1634	1501	1798

These estimates are high because they do not include the shielding effect of the towers, guy wires, and transmitter building. However, they indicate that areas exist around the transmitter building and in the antenna field where the electric field will exceed the 614 V/m limit.

The electric field on the roof would be considerably higher than that given in table 1 because of the close proximity of the feeder cages. However, the roof is off limits while the transmitter is operating.

The towers that hold up the top-load are all grounded and have grounded guy wires (figure 4). The towers and guy wires shield the ground area around the tower bases so that the average field in these areas is very low.

The area inside of the towers is shielded by the tower legs and braces so the electric field inside the towers is also low.

Outside the tower, the fields are higher. Near the tower base, these fields are low because of the shielding of several layers of guy wires. Higher up the tower, the electric fields outside the tower are greater because of increasing proximity to the active top-load and the presence of fewer shielding guy wires.

The maximum electric fields are outside the tower in the tower top area above the top guy wire. For a tower with an active panel attached, these fields are several kV/m.

The conclusion of the above discussion is that areas exist on the ground around the transmitter building and at the tower tops where the electric fields are expected to exceed the 614 V/m limit.

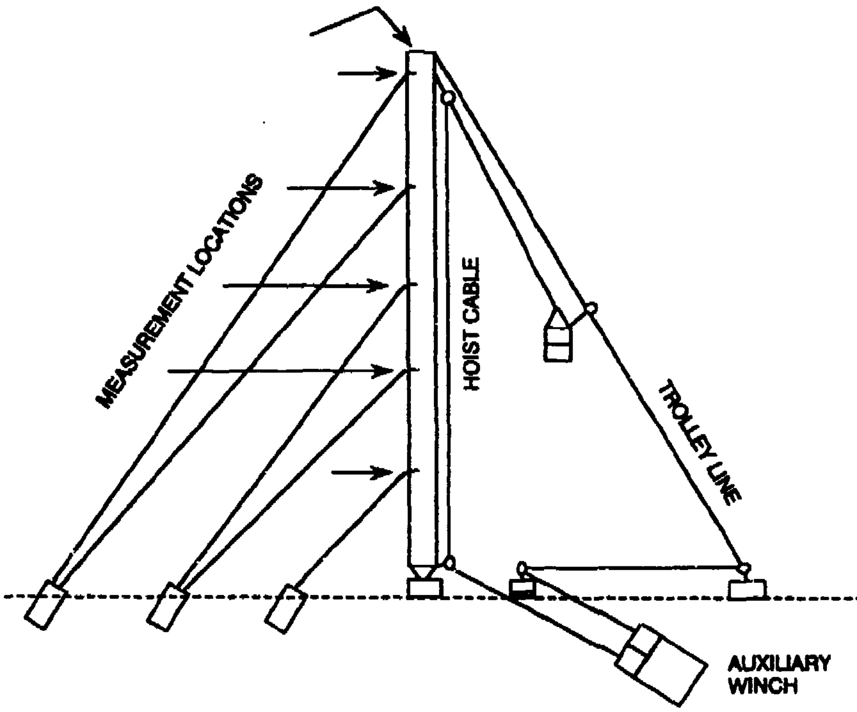


Figure 4. Typical tower guy system and auxiliary winch rigging.

MAGNETIC FIELDS

The limit for H-field exposure in IEEE C95.1 (1991) is 167 A/m; the estimates in appendix A show that no region is normally accessible while operating where one would find this field level. The roof area near the bushings and under the 4-wire cage bus could have fields of this magnitude, but they are not accessed while operating.

INDUCED CURRENTS

A free-standing object immersed in an electric field (e.g., a person, building, tower, pole, etc.) has an induced current flowing to ground. This current can be calculated from (1) the open circuit voltage that would be induced on the object if it were insulated from ground, and (2) the impedance to ground the object would have if it were insulated from ground. The open circuit voltage is given by

$$Voc = E*he ,$$

where E is the electric field and he is the effective height of the object.

The induced current is given by

$$Ii = Voc/Z ,$$

where Z is the magnitude of the object's impedance.

The effective height for a linear object, such as a person or tower, can be estimated quite accurately by half the physical height. For a tall person, this would be about 1 meter. The capacitance of linear objects depends somewhat upon aspect ratio. For average people, a good estimate is 30 pF/m. At 19.8 kHz, this implies an impedance of 134,000 ohms.

Using the above parameters for a free-standing person with excellent electrical connection to ground, the body current limit of 19.8 mA would not be reached until the electric field reached 2653 V/m, more than 4 times the field limit in the standard. The actual currents are usually several times less than estimated by the above procedure because shoes usually act as insulators reducing the current.

Therefore, even though the fields are expected to exceed the 614 V/m limit, the body current limit is not expected be exceeded for a free-standing person (i.e., not touching any object) anywhere on the ground around the transmitter building.

However, if the person touches an insulated object, their body will provide the a path for the current to flow to ground. In this case, the current that flows is dictated by the size of the object and the impedance to ground of the person. For large objects, these currents can be considerably greater than for a free standing person alone.

MEASUREMENTS

The NRaD team was primarily responsible for the measurements on the towers. This report includes the tower measurements. In addition, there were a few other areas where NRaD assisted the other teams. Those measurements are also reported here. In general, the major share of the measurements on the ground and in and around the transmitter building will be reported elsewhere by RAN and BUMED (Rowell 1993).

TOWER DESCRIPTION

All the towers have a triangular cross section when viewed from above. The faces of the tower are numbered 0, 1, and 2. The 0 face is always perpendicular to the radius from T0; the numbers increase clockwise when viewed from above. The tower legs are similarly numbered with the 0 leg opposite the 0 face etc.

Inner Towers

The inner towers have 5 guy levels (figure 4). Rest platforms are located every 60 feet on the inner towers, and ladders are located between rest platforms inside the tower.

The inner towers are placed such that the 0 face is on the side away from T0 (figure 5). The inner towers have two winches at the base. The winches are connected to the two hoist cables for the panels on either side of the tower. These hoist cables run up the outside of the tower in the center of faces 1 and 2. The hoist cables are held off from the tower by several outrigger arms, which are about 6 feet long near the bottom of the tower and abut 2 feet long near the top.

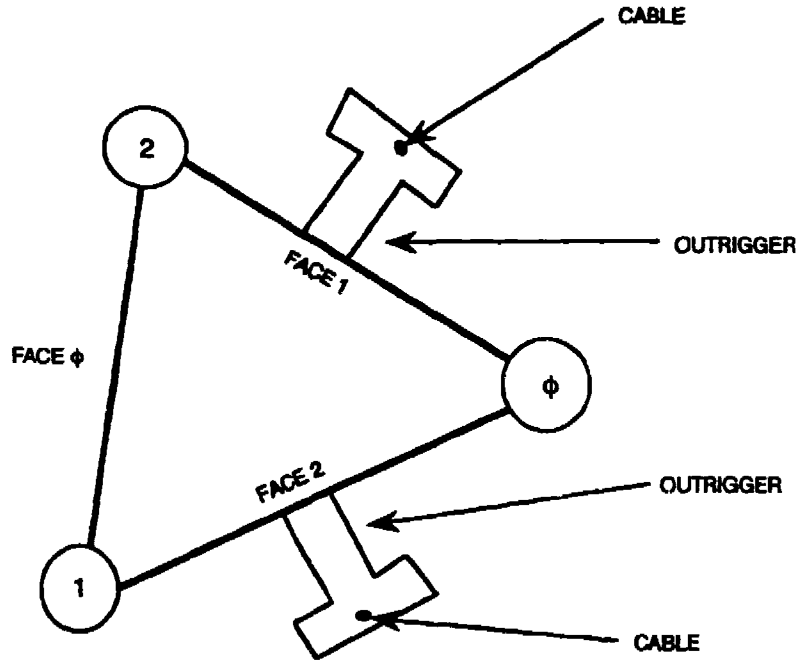


Figure 5. Top view inner tower.

The section at the tower top, the sheave platform (figure 6), is where the hoist sheaves are located. Much of the tower maintenance work is performed here. The sheaves extend out from the center of panels 1 and 2. Measurements were done at the platform center and at several locations outside the tower, including on top of the tower. These locations, most of which are indicated in figure 6, are accessed by riggers for maintenance.

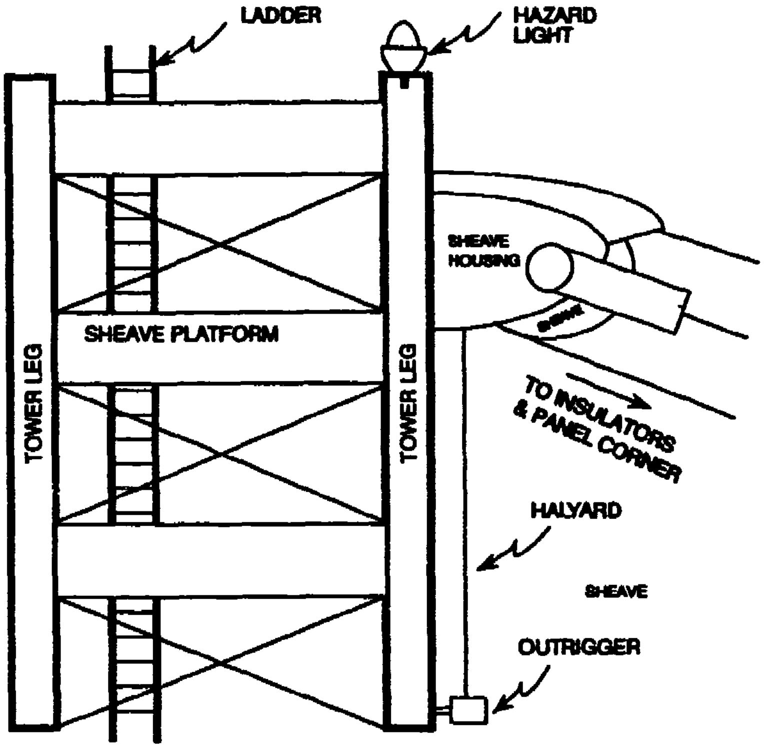


Figure 6. Tower top area.

Outer Towers

The outer towers, because they are shorter, have only 4 guy levels. Outer towers have a similar configuration to the inner towers with ladders and rest platforms, and rest platforms are located every 80 feet.

The outer towers are placed such that the 0 face is on the side towards T0 so that the single sheave at the top of an outer tower is pointing at T0 (figure 7). The outer towers have a sheave platform similar to the inner towers but with only one sheave.

The outer tower only has one winch at the base. The winch connects to the hoist cable going up the 0 face to the sheave. Like the inner towers, the hoist cable is held off from the tower by several outrigger arms.

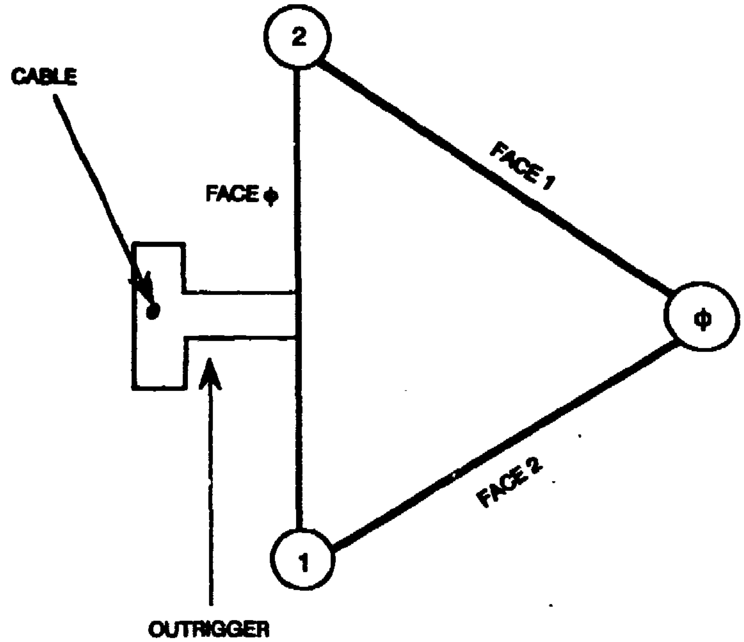


Figure 7. Top view of outer tower.

POLARIZATION

The polarizations measured are shown in figure 8 and described below

Vertical:	Ev, Hv	Vertical
Normal:	En, Hn	Perpendicular to Tower Face
Horizontal parallel:	Ehp, Hhp	Horizontal and parallel to tower face
Maximum:	Emax, Hmax	Maximum over polarization and position

Measurements were done at the platform center and at several locations outside the tower including on top of the tower. These locations (most of which are indicated in figure 8) are accessed by riggers in the course of maintenance operations.

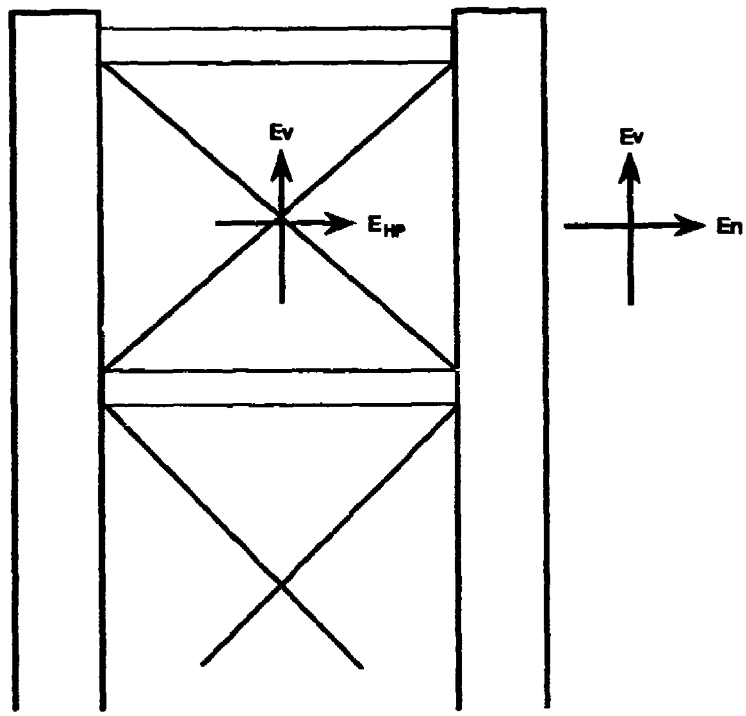


Figure 8. Field polarizations measured.

MEASUREMENT EQUIPMENT

The measurements of the electromagnetic fields on the towers were done by using a Holaday HI 3603 field strength meter and HI 3616 fiber-optic remote control (provided by John Rowell of ADF). This meter measures both E and H fields. The maximum measurable E field is 2000 V/m, and the maximum measurable H field is 2 A/m. The tower was climbed carrying the measurement equipment and measurements made at appropriate levels.

Body currents were determined through direct in-line current measurements. We used an HP 3468 digital multimeter that was shielded in a custom-made copper box fitted with a shoulder strap for carrying. Body currents were also measured with two custom in–line meters provided by NAMRL.

The currents in the winch cables were measured by using the shielded HP meter in conjunction with one of two different clamp-on current probes. The smaller probe was a 3 1/2-inch fluke clamp-on ammeter specially modified to be shielded and terminated in 50 ohms for operation at VLF. The larger clamp-on probe was an 8-inch Genestron also terminated in 50 ohms. These were calibrated at NRaD by using a noninductive resistor.

Measurements of strong magnetic fields were made by using a custom-made Watt Engineering blue-loop antenna connected to the HP meter. The loop is well shielded with 60 turns wound in an oval about 1 by 2 feet. This system was calibrated by using the NRaD Helmholtz coil. Calibration data on the NRaD equipment are given in appendix B.

TOWER MEASUREMENTS

Measurements

Measurements were taken on inner tower T2 and outer tower T1 for all configurations. The baseline measurements for the normal 6-panel mode were taken at "maximum power." This means the full 2-MW transmitter power is fed into the antenna, which corresponds to 1.6-MW radiated. The antenna current for this power level is 2600 A on 19.8 kHz.

When the antenna was in the 6-panel mode, power had to be reduced considerably to bring the field at the tower top within measurement range of the meter. A single PA was used for the measurements at reduced power level. Minimal waveform distortion was observed with an antenna current of 685 A. The fields measured at reduced power were then scaled by the factor 2600/685 to determine the fields at maximum power.

For the 4- or 5-panel modes, the power is limited to 1-MW radiated ("full power"). Because the fields on an isolated tower are considerably reduced (especially on the top), no power reduction was required for these measurements.

Inner tower T2 is connected to panel A on one side and panel B on the other side. Measurements were made on this tower when it was isolated by placing both panels, A and B, in hybrid mode, or by having panel A down and panel B in hybrid. Measurements were also made on this tower in the 5-panel mode with panel B active and panel A inactive by being on the ground or in hybrid mode.

Outer T1 is at the end of panel A. Measurements were made on this tower with panel A (1) active, (2) hybrid, and (3) down.

The configurations measured are listed in table 2, with the table reference indicating the location of the data.

Table 2. Configurations measured.

Tower	Configuration	Table
T1	6 panel	4
T1	5 panel – 1 down	10
T1	5 panel – 1 hybrid	9
T1 winch	both 5 panel modes	10
T2	6 panel	3
T2	5 panel – 1 hybrid	5
T2	4 panel – 2 hybrid	6
T2	4 panel – 1 hybrid	7
T2 winch	4 panel all modes	8

The first set of measurements were taken on T2. The transmitter was at maximum power (2600 A). The fields in the vicinity of the tower base are low (around 50 V/m) due to the shielding of the grounded tower and grounded guy wires. Measurements were taken at rest platform locations just above each guy wire.

The measurements consisted of measuring the E and H fields in all three polarizations at the following positions: (1) in the center of the rest platform, and (2) outside the center of each tower face at a height of about 4 1/2 feet above the rest platform and about 2 feet outside the tower face. On the faces where the hoist cable is located, we measured approximately 1/2 way between the tower face and the cable. In several instances, we also measured outside of the hoist cables. These measurements are summarized in table 3.

At the tower top in the 6-panel mode at full-power, the outside electric fields were stronger than could be read by the meter. We reduced transmitter power to 685 A in single PA mode. The antenna current waveform was observed to have very little distortion, and the fields were within the dynamic range of the meter. These measurements are also summarized in table 3.

The magnetic fields on T2 in the 6-panel mode at maximum power were expected to be greatest for any tower, except T0. As expected, the measurements show that the magnetic fields are far below the allowable standard for this worst case condition. Consequently, measuring the magnetic fields for any other modes was not necessary.

While we measured on T2, the other teams were measuring electromagnetic fields in and around the transmitter building. Following completion of our measurements at the top of T2 and their measurements on the ground, the antenna was reconfigured by placing panel A in hybrid mode. We made another set of measurements at the tower top (table 4).

Following that, the antenna was placed in 4-panel hybrid mode by putting panel B in hybrid and measurements were made at the tower top. We then climbed down the tower, making measurements at the same locations as before when we climbed up the tower (table 5).

The measurement procedure on T1 was similar and the results are summarized in the tables.

Discussion

In the 6-panel mode at maximum power, the electric field levels outside the tower at locations above the first guy level were well above the limit set by the standard. For example on the inner tower T2 (table 3), En (figure 8) on face 0 of T2 exceeded 1000 V/m at all locations measured. The fields on the tower top were very high; about 8000 V/m in some cases. At levels below the first guy, the fields outside the tower are below the hazard level defined by the standard.

In the 6-panel mode at maximum power on the outer tower T1 (table 4), En outside the tower was below the hazard limit for locations below the 3rd guy level. For locations above the 3rd guy level, En exceeded the standard limit and in fact was above 1000 V/m. On the tower top, the fields were very high (in some cases exceeding 6000 V/m).

Personnel on the towers are advised to remain inside the faces of the towers when the transmitter is in the 6-panel mode at all locations above the first guy level.

When the towers are isolated, the fields inside and outside are such that there is no hazard anywhere on the tower as defined by the IEEE standard.

An inner tower can be isolated by rigging in a 4-panel mode with one down, one hybrid, or both hybrid. The data for these cases are given in tables 6 and 7. In both of these cases, the only locations where the fields exceed the 614 V/m limit are where the field is concentrated by a sharp edge such as a ladder top or edge of the sheave housing. Even though the fields exceed the limit in a local area, averaging over the extent of a person's body, as specified by the standard, indicates that there is no hazard. Body currents were measured at all working locations indicated by the riggers on the isolated tower. No significant body currents were measured.

An outer tower can be isolated either by placing the associated panel in hybrid mode or by lowering it. The data for these cases are given in tables 9 and 10. An outer tower has lightning rods that partially shield the tower top. In this case, the area just above the hazard light was the only location where the 614 V/m was exceeded. This is a small area and the average over the body extent indicates that no hazard exists. Again, body currents were measured and no significant levels were observed anywhere.

AUXILIARY WINCHES

In order to perform maintenance on the towers, it is necessary to rig an auxiliary winch and bucket. The purpose of this rig is to hoist up the tower the materials, tools, and equipment needed for maintenance. The maintenance includes painting, greasing the halyard cables, and replacing worn or damaged parts of the tower and hoist system. To work on the towers while transmitting, this auxiliary winch must be installed and operating.

The typical rigging for the auxiliary winch and bucket hoist is shown in figure 4. The winch uses two separate drums. One drum hauls the hoist cable that lifts the bucket; the second drum controls the trolley-line tension that guides the bucket and keeps it tagged out from the tower. The entire loop is grounded by a good ground connection at the winch.

The hoist cable plus trolley line constitute a large closed loop. This loop has a current induced by the magnetic field enclosed by the loop. The magnitude of the induced current depends upon the magnitude of the magnetic field normal to the loop plane, the loop area, and the loop inductance. The current path can change; for example, if there is momentary contact of the cable to the tower, the current would tend to flow mostly in the tower. Momentary or brush contact can result in sparking, and damage to the cable if the currents are large enough. Part of the reason is that the current can be concentrated in a small portion of the outside area of the cable.

During the measurements made in 1978 at 22.3 kHz, we determined that the maximum current for conditions existing at that time was about 10 A. We determined that this was safe as this current did not damage the cable during momentary make or break contact with the tower or ground.

For the present frequency and configuration, the maximum current observed through the cables was 2 A. This occurred when the winch was rigged on an inner tower (table 8). Almost all the current readings were less than 1 A. Samples of the hoist and trolley cable were obtained and taken to the Forestport High Voltage Test Facility to measure the VLF fusing currents of the outer wires. The details of these measurements are given in appendix C. The fusing currents of a single strand are considerably higher than the total loop currents. Based on this, it is safe to operate the winch in this configuration on an isolated tower.

Table 3. T2 6-panel mode (Part 1).

Wed 21 April 1993
Tower 2
6-panel mode
2600 A

E (V/m), H (A/m)

NRaD Meters

1 Platform above 2nd guy	Face 0 No Cable	Face 1 B Cable	Face 2 A Cable	Inside Tower	
Field	NE	SE	NW		
En	3000	400	400		
Ev	60	40	40	25	
Hmax	0.18	0.11	0.102	0.48	Next to Leg 2

Haloday meter

1 Platform above 3rd guy (outriggers)	Face 0 No Cable	Face 1 B Cable	Face 2 A Cable	Inside Tower	H3616
Field	NE	SE	NW		
En	1133	749			
Ev	765	115	45		
Ehp	950	745	498		

Haloday meter

1 Platform above 4th guy	Face 0 No Cable	Face 1 B Cable	Face 2 A Cable	Inside Tower	H3616
Field	NE	SE	NW		
En	>2000	1200	1450		
Ev	1600	950	950	50	
Ehp	1950	925	1200	35	
Hn	0.195	0.28	0.015		
Hv	0.047	0.037	0.045	0.035	
Hhp	0.48	0.28	0.3	0.093	

Note: E in V/m, H in A/m.

Table 3. T2 6-panel mode (Part 2).

E (V/m), H (A/m)

Haloday meter

Meas Ias = 685 A H3616

Sheave Platform	Face 0 No Sheave	Face 2 A Sheave					Face 1 B Sheave				Inside Tower
Field	NE	Left	Right	Above	Front	Under	Left	Right	Above	Front	
Ea	1640	900	1100		>2000		830	1470		1708	
Ev	1500	1293	386	1256		36	120	350	950		
Ehp	818			329					900		
Emax											<50
Hn	0.0185	0.0386	0.0265			Hn	0.076	0.08			
Hv	0.005	0.0971	0.1	0.0523		Hv	0.085	0.105	0.052		
Hhp	0.0774		0.037			Hhp			0.0125		
						Hmax					<0.1

Calc Ias = 2600 A H3616

	Face 0 No Sheave	Face 2 A Sheave					Face 1 B Sheave				Inside Tower
Field	NE	Left	Right	Above	Front	Under	Left	Right	Above	Front	
Ea	6225	3416	4175		>7591		3150	5580		6463	<0.05
Ev	5693	4908	1465	4767		137	455	1328	3606		
Ehp	3105			1215					3416		
Emax											<0.05
Hn	0.0702	0.1465	0.1006				0.0607	0.3036			<0.190
Hv	0.0190	0.3686	0.3796	0.1985			0.3226	0.3985	0.1974		
Hhp	0.2938		0.1404						0.0474		

Tower Top	Meas No Cable	Ias = B Cable	685 A Cable	A Platform	Haloday meter H3616	Entire
	NE	SE	NW	Center	0 Leg	Area
Em(v)		1300	1200	1650	1550	
Eh	550					
Hmax						0.07

Table 3. T2 6-panel mode (Part 2) (Continued).

Calc Ias = 2600 A

Tower Top	Face 0 No Cable	Face 1 B Cable	Face 2 A Cable	Platform	Haloday meter H3616	Entire
	NE	SE	NW	Center	0 Leg	Area
Em(v)		4934	4555	6263	5883	
Eh	2088					
Hmax						0.266

Note: E in V/m, H in A/m.

Table 4. T1 6-panel mode (Part 1).

4/28/93 Tower 1 6-panel mode, Maximum Power, 19.8 kHz

E (V/m), H (A/m)

Ias = 2586

1st Outrigger platform	Face 0	Face 1	Face 2
Ev	20.8	73.3	72.5
Ehp	48.4	102.7	78.4
En	68.6	112.9	112.5

Ias = 2560

1st level above 2nd guy	Face 0	Face 1	Face 2
Ev	108.9	315	327
Ehp	222	378	323
En	275	480	527

Ias = 2565

1st level above 3rd guy	Face 0 A Cable Inside Cable	Face 0 A Cable Outside Cable	Face 1 No Cable	Face 2 No Cable
Ev	432	1390	720	771
Ehp	560		930	756
En	580	>2000	1125	1190

Ias = 2560

Top Outrigger Level	Face 0	Face 1	Face 2
Ev	516	785	780
Ehp	600	1040	850
En	710	1220	1170

Note: E in V/m, H in A/m.

Table 4. T1 6-panel mode (Part 2).

Meas Ias = 720

Sheave Platform	Face 0 Sheave A.......				Face 1	Face 2
	Left	Right	Above	Edge		
Ev	675	285	660		230	360
Ehp	30	80	220		595	378
En	308	436		440	756	830

Calculated for Ias = 2600

Sheave Platform	Face 0 Sheave A.......				Face 1	Face 2
	Left	Right	Above	Edge		
	2438	1029	2383		831	1300
	108	289	794		2149	1365
	1112	1574		1539	2730	2997

Meas Ias = 720

Tower Top	1 Meter above.......					1 foot above Ladder	2 feet above Light
	Platform Center	Face 0 Corner	Face 1 Center	Face 2 Center	Sheave A Center		
Ev	550	280	365	155	340	1200	1700

Calculated for Ias = 2600

Tower Top	1 Meter above.......					1 foot above Ladder	2 feet above Light
	Platform Center	Face 0 Corner	Face 1 Center	Face 2 Center	Sheave A Center		
Ev	1986	1011	1318	560	1228	4333	6139

Note: E in V/m, H in A/m.

Table 5. T2 5-panel mode.

Wed 21 April 1993
Tower 2
5-panel hybrid (A Hybd)
Ias = 597 amps
E (V/m), H (A/m)

Haloday meter
Meas Ias = 696 A H3616

Sheave Platform	Face 0 No Sheave	Face 2 A Sheave (Hybd)					Face 1 B Sheave (Active)				
Field	NE	Left	Right	Above	Front	Under	Left	Right	Above	Front	Under
En	1030	985	925		1320		500	425		1550	
Ev	345	115	725	870			70	80	920		
Ehp	610			515					540		
Emax						308					308

Calc Ias = 2063 A

Sheave Platform	Face 0 No Sheave	Face 2 A Sheave (Hybd)					Face 1 B Sheave (Active)				
Field	NE	Left	Right	Above	Front	Under	Left	Right	Above	Front	Under
En	3053	2920	2742		3913		1482	1260		4594	
Ev	1023	341	2149	2579			207	237	2727		
Ehp	1808			1527					1601		
Emax						913					913

Meas Ias = 696 A

Tower Top	1 M above Platform Center	1 M above 0 Leg	1 M above 2 Leg	2' Outside Twr @ To Sheave	2' Outside Twr @ Head Sheave
Emax	840	730	770	560	600

Calc Ias = 2063 A

Tower Top	1 M above Calc Platform Center	Ias = 1 M above 0 Leg	1 M above 2 Leg	2' Outside Twr @ T0 Sheave	2' Outside Twr @ Head Sheave
Emax	2490	2164	2282	1719	1778

Note: E in V/m, H in A/m.

Table 6. T2 4-panel hybrid.

4-Panel Hybrid (Panels A and B Hybd)

Meas Ias = 2148 A

Tower Top	1 M above Platform Center	1 M above 0 Leg	1 M above 1 Leg	1 M above 2 Leg	2' Outside Twr @ T0 Sheave	1' Above Ladder Top
Emax	560	520	520	60	920	1425

Meas Ias = 2148 A

Sheave Platform	Face 0 No Sheave	Face 2 A Sheave (Hybd)					Face 1 B Sheave (Hybd)				
Field	NE	Left	Right	Above	Front	Under	Left	Right	Above	Front	Under
En		325	250	500			290	284	450		
Ev		85	70				330	90			
Ehp				188					260		
Emax					700	431				580	757

Body Current measurements were made as follows:

Person standing on tower top and ladder top
Person standing on sheave top and tower
Person in contact with tower installing top sheave
Person in contact with tower and halyard under both sheaves

All currents were below the measurement threshold of 3 mA.

Top Outrigger Platform	1' Outside A Panel Cable	1' Outside B Panel Cable
Emax	365	373

Ias = 2148 A

1 Platform above 4th guy level	Face 0 No Cable	Face 1 B Cable	Face 2 A Cable
En	218	138	119
Ev	139	43	60
Ehp	135	70	104

Measurements 1/2 way between tower face and cable

Ias = 2149 A

1 Platform above 3rd guy level	Face 0 No Cable	Face 1 B Cable	Face 2 A Cable
En	108	52	35
Ev	59.5	35	20.5
Ehp	65	27	33

Measurements 1/2 way between tower face and cable

Note: E in V/m, H in A/m.

Table 7. T2 4-panel mode – 1 hybrid (Part 1).

T24M1DN
Tower 2, 4/24/93
4-Panel Mode, A Down, B Hybrid
Ias = 2083 A

First outrigger level
Body currents measured between man and cable and man and tower, with man standing outside tower on both outriggers.
All currents measured less than the 2 mA measurement threshold.

First Outrigger Level	Face 0 No Cable	Between Cable and Tower Face 1 B Cable	Between Cable and Tower Face 2 A Cable	Outside Cable Face 1 A Cable
Ehp	12.0	7.9	6.6	16.4
Ev	10.7	5.3	3.6	17.3
Ea	16.6	9.3	8.5	25.0

1st Platform above 2nd guy level	Face 0 No Cable	Between Cable and Tower Face 1 B Cable	Between Cable and Tower Face 2 A Cable
Ehp	30.5	20.0	17.8
Ev	32.0	16.5	17.2
Ea	32.0	29.3	25.9

1st Platform above 3rd guy level	Face 0 No Cable	Between Cable and Tower Face 1 B Cable	Between Cable and Tower Face 2 A Cable
Ehp	70.5	32.4	26.5
Ev	62.5	18.5	19.6
Ea	70	25.8	24.5

1st Platform above 4th guy level	Face 0 No Cable	Between Cable and Tower Face 1 B Cable	Between Cable and Tower Face 2 A Cable
Ehp	124.5	72.4	35.5
Ev	129.5	60.8	54.0
Ea	138.5	63.0	48.2

All currents were below the measurement threshold of 3 mA.

Note: E in V/m, H in A/m.

Table 7. T2 4-panel mode – 1 hybrid (Part 2).

Sheave Platform	Face 0 No Cable	Face 1 B Sheave			Face 2 A Sheave		
		Left	Right	Above	Left	Right	Above
Ehp	518			460			424
Ev	333	9	5	290	40	100	360
En	480	520	590	700	344	180	900

Tower Top	1 meter above				1 Foot Above Ladder
	Center	Leg 0	Leg 1	Leg 2	
Emax	560	370	170	435	1650

At Head Sheave Location	Face 0 No Cable
Ehp	152
Ev	12
En	30

Note: E in V/m, H in A/m.

Table 8. T2 winch rigging measurements 4-panel mode – 1 hybrid (Part 1).

T2 – 4-panel mode A down, B hybrid, 4/24/93
4-panel mode – 1 hybrid

Winch rigging measurements
Voltage in V, current in A

	Head sling sheave Side 1	Head sling sheave Side 2	Winch Rope to Tower Winch Side	Winch Rope to Tower Load Side
Voc			20.0	
Iss	0.001	0.0014	0.006	0.005

With cage at top, tagged out about 1'	Trolley Line	Load Line Load Side	Load Line Winch Side
Icable	0.8	0.008	0.006

Cage at 1st guy level, tagged out maximum	Trolley Line	Hoist Cable
Icable	0.444	0.5

Current thru clyde hoist ground rod

Cage in close at store position	4 A
Cage at maximum tag	0.06

Current thru trolley line at anchor block

Above sheave	0.454
Below sheave	0.458

Note: E in V/m, H in A/m.

Table 8. T2 winch rigging measurements 4-panel mode – 1 hybrid (Part 2).

T2 – 4-panel mode A down, B hybrid, 4/24/93
4-panel mode – 1 hybrid

4/27/93 4-Panel Hybrid 10:30
Ias = 2148 A

Cage about 40-feet off ground and tagged out to maximum. Body currents between a person and cage were measured at 1–8 mA.

Trolley line currents were measured at 0.6 A. This current varies from 0.2 A to 1 A as the tag angle increases. Above the cage, this current divides between hoist cable and trolley line cable when there is good contact between cage and trolley line. The contact provided by the flexible sheave hardware was intermittent providing a path for make/break currents of about 0.3 A. This was discovered by observing some arcing. If the connection was intermittent, this could lead to excessive body currents under certain circumstances. For this reason, we rigged up a ground strap connecting the trolley line sheave to the cage, which eliminated the problem.

About 0.1 A flows into the load block through sheave and shackle.

In Cage 3.4 to top tagged out maximum

Trolley sheave ground measures trolley line sheave measures 0.243 A
Trolley line measures 0.6 A

At top in Cage 12:27

Hoist cable measure	0.6
Trolley cable current	0.8

Note: E in V/m, H in A/m.

Table 9. T1 5-panel hybrid (Part 1).

T15PHYBD
4/28/93 Tower 1 5-panel hybrid mode, full power, 19.8 kHz

Ias = 2065

1st Outrigger platform	Face 0	Face 1	Face 2
Ev	2.0	8.6	7.5
Ehp	5.0	12.0	10.0
En	7.0	15.0	17.0

Ias = 2065

1st level above 2nd guy	Face 0	Face 1	Face 2
Ev	8.0	31.0	38.0
Ehp	20.0	30.0	43.0
En	25.0	60.0	60.0

Ias = 2066

1st level above 3rd guy	Face 0 A cable Inside Cable	Face 0 A cable Outside Cable	Face 1 No Cable	Face 2 No Cable
Ev	171.0	86.0	69.0	75.0
Ehp	120.0	85.0	75.0	77.0
En		330.0	126.0	140.0

Ias = 2066

Top Outrigger Level	Face 0 A cable Inside Cable	Face 0 A cable Outside Cable	Face 1 No Cable	Face 2 No Cable
Ev	3.0	8.0	12.0	10.0
Ehp	35.0	3.0	30.0	30.0
En	8.0	34.0	10.0	20.0

Note: E in V/m, H in A/m.

Table 9. T1 5-panel hybrid (Part 2).

Ias = 2064

Sheave Platform Measurements	Face 0 ASheave......						
	Left	Right	Above	Edge	Under	Face 1	Face 2
Ev	12.0	21.0	585.0		115.0	100.5	110.5
Ehp	275.0	250.0	86.0		73.0	178.0	200.0
En	127.0	112.0		435.0	160.0	400.0	375.0

Ias = 2064

Tower Top Measurements	1 meter above......					2 Feet Above Ladder	Just Above Light
	Platform Center	Face 0 Center	Face 1 Center	Face 2 Center	Sheave A Center		
Ev	280	75	150	55		278	650

Note: E in V/m, H in A/m.

Table 10. Tower 1 winch measurements.

T1WINCH

4/29/93 Tower 1 5-panel hybrid mode, full power, 19.8 kHz

Top Tower Measurements 13:57 Ias = 2068

No measurable open circuit voltage or short circuit current between cable and tower as cable approaches tower

Trolley line currents 0.16

Top Outrigger Platform
Cage at Platform, Winch Cable rigged on Face 2

	Face 0 Inside	Face 0 Outside	Face 1	Face 2
Ev	13	78	89	95 Near Cage
Ehp	44		108	190 Near Cage
En	68	220	142	95 Near Cage

Winch Measurements T1 5-panel mode, Panel A Down

4/29/93 10:51 Ias = 2060

Cage 35–40 feet above ground, maximum tag
Trolley line and hoist line currents are all in noise (<0.04 A)

Tower Top 11:42 Ias = 2060

Trolley line current varies from 0.04 A at minimum tag to 0.14 A at maximum tag
Head sling, top sheave sling, and hoist line currents are all in noise.

Negligible body currents measured at all locations by personnel accessible

Note: E in V/m, H in A/m.

Dr. Olsen (NAMRL) found some sparking in the vicinity of the trolley pulley on the bucket caused by a poor connection between the pulley case and the cage. When no connection existed between the cage and the trolley line, all the loop current flowed in the trolley line. When a connection did exist, the current was shared between the trolley line and the hoist cable. When the contact was made or broken, sparking was observed. Furthermore, when there was no connection, a person touching both the cage and the trolley line could get a shock. The problem can be eliminated by providing a ground between the trolley line pulley casing and the cage. A temporary ground was made by using a piece of braid and two vice grips. A more permanent ground should be installed.

DISCONNECTION OF INSULATORS

Tests were made at the base of an outer tower in the 5-panel mode to determine if it was safe to disconnect the insulator string and place the load block in the anchor position. For this procedure, the crane was connected to the load block and then moved to reposition the load block. The connection was then transferred to a truck, which also moved around in order to position the load block in the anchor. Because the crane and truck were not grounded, body currents in excess of 19.8 mA were measured depending upon the ground connection of the person. If the person touched the truck or the crane and the panel, which was laying on the 3000 barrels, considerably more current would flow. This problem was eliminated by wearing dry gloves.

When the transmitter is operating, the insulator disconnection procedure is carried out only on an outer tower. The riggers involved in handling the insulators or anything connected to the electrically ungrounded halyard, load block and crane or truck, should wear dry gloves.

CRANE MEASUREMENTS

Under Feeder

The crane was parked under an active feeder while the transmitter was operating with the antenna in the 4-panel mode. The fields where the crane was parked were about 1100 V/m. The crane was parked with the boom down. When the outriggers were not down and the crane was electrically floating, body currents of up to 60 mA would flow, depending upon the person and the insulating quality of his or her shoes. When the outriggers were placed down, the currents were reduced to levels below the limit specified by the standard. When the crane is parked anywhere near the horizontal feeders, the outriggers should be put down.

Under a Panel

Body current measurements were taken between the load ball of the crane cable and ground with the crane positioned under the center of panel F and the transmitter operating in the 6-panel mode. The average electric field at this location was 320 V/m. When the crane was grounded by placing the outriggers in the down position, the body currents measured were below our measurement level and well below the limit of the standard. There is some possibility of incomplete contact between the cable and the crane. Thus, if the winch is to be used in the area under an active panel, standard grounding procedures should be used. It is especially important to ground the load before anybody touches it.

POWER AMPLIFIER (PA) WINDOWS

The PAs have observation windows that the operators look through periodically to ensure that the cooling water to the tubes has not begun leaking. The observer's face and eyes must be placed as close as possible to the glass and the viewing area shadowed by using the hands. The Holaday meter is not configured to measure vertical polarization close to the window. The NRaD meter was used to measure fields next to the glass. Only one window had not been shielded by placing fly screen behind the window. The shielded windows had very low fields of less than 10 V/m.

The NRaD E-field meter measured the one unshielded window measured over 2 kV/m. This meter has a probe dimension of about 3 inches. The fields were measured next to the glass at the center of the window. According to the standard, the minimum distance between the measurement probe and any electrically conducting object should be three probe lengths. Our measurement violated this criteria slightly. When this criteria is violated, the indicated value usually is somewhat greater than reality.

The field at the glass center exceeds the 614 V/m criteria of the standard. For this particular exposure situation, the standard is somewhat ambiguous (e.g., much higher fields than 614 V/m are allowed for short time exposures less than 5 minutes). Much higher fields are also allowed for partial body exposure, depending upon the part of the body exposed. For exposure of the eyes or the testes, no relaxation of the standard is allowed. Thus, it is prudent to install screening on all the PA windows. For practical reasons (e.g., to facilitate cleaning) the specially made windows with screening wire imbedded in the glass should be installed.

CAPACITORS

Capacitor Room

Several large capacitors are in the capacitor room adjacent to the helix house. Some of these capacitors are in series with the circuit and some of them are in shunt across the circuit. The station's technical personnel indicated that they had experienced shocks and observed heavy sparking while working in the capacitor room of the inactive helix house.

During investigation of this problem, we experienced nuisance shocks in several places. Short circuit currents of 20 A were measured between the insulated terminal of the capacitor and the capacitor case, and 60 A between the capacitor case and the floor grating. Body currents would be less due to the insulation effect of the skin and shoes. Body currents were not measured due to the large magnitude of the currents. This area is considered hazardous and should be off limits while operating the transmitter. The area can be inspected from the open door while operating without any risk of contacting the capacitor case and floor grating.

PA Tank Circuit

Site technical personnel had observed sparking and nuisance shocks when working on the capacitors in an inactive PA tank circuit while the transmitter was operating. This situation was investigated by making body current measurements in PA 1 while PAs 2, 3, and 4 were operating. We found that when solid ground connections were made by using braid and vice grips, no measurable body current existed and nuisance shocks were not a problem.

CONCLUSIONS/RECOMMENDATIONS

A joint RADHAZ survey at VLF HEH has been completed. According to the new standard, most areas normally accessed by personnel while transmitting do not result in hazardous exposure from electromagnetic fields. The NRaD portion of the survey and this report addresses primarily working on the towers while the transmitter is operating.

Measurements on the towers show that all locations inside any tower (except T0) can be accessed safely for all modes of operation. In the 6-panel mode, personnel should remain inside the confines of the tower at locations above the first guy level.

At full power (1 MW radiated), an isolated tower may be accessed anywhere on the tower, including the outside and the tower top area, without hazard from electromagnetic fields.

Measurements on the auxiliary winch and cables used to hoist equipment up the tower show that this rigging can be safely installed and operated on any isolated tower while the transmitter is operating at full power. Normal grounding and bonding procedures must be followed to keep currents from making and breaking contact across shackles and pulleys. In particular, a ground connection must be attached between the trolley line pulley and the hoist cage.

Body currents in excess of the standard can occur when touching an ungrounded crane. Personnel should not be allowed to come in contact with an ungrounded crane. For most operations, including parking, this problem can be eliminated by lowering the outriggers. For operations when the crane needs to move, the outriggers cannot be lowered. Thus, personnel who might touch the crane or anything connected to the crane should continue the practice of wearing dry gloves, and shoes or boots that provide good insulation. Rubber soled footwear and dry gloves significantly increase the impedance to ground and reduce the possibility of nuisance shock.

Because the transmitter operators place their eyes directly in the high field near the PA windows, it is recommended that these windows be screened. For practical reasons (e.g., to facilitate cleaning), specially made windows with screening wire imbedded in the glass should be installed. Until that installation can be completed, the screening presently installed should remain in place. In addition, the one unscreened PA window should be provided with a screen.

The possibility of shocks and body currents significantly greater than the standard allows makes the inactive capacitor room a hazardous area. This area should be declared off limits while the transmitter is operating. The area can be safely inspected from the open door with the transmitter operating.

Personnel can safely work in the tank circuit of an inactive PA while transmitting, provided proper grounding procedures are used.

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ACRONYMS AND ABBREVIATIONS

ADF	Australian Defence Force
ADI	The Australian Contractor maintaining HEH
ANSI	American National Standards Institute
BUMED	Bureau of Medicine and Surgery
CNCTC	Naval Computer and Telecommunications Command
EAVG	Average Electric Field
EF	Electric field
HEH	Harold E. Holt
HERP	Hazardous Electromagnetic Radiation to Personnel
IRPA	International Radiation Protection Association
MPE	Maximum Permissible Exposure
NAMRL	Naval Aerospace Medical Research Laboratory
NAVELEXCEN	Naval Electronic Systems Engineering Center
NCCOSC	Naval Command, Control and Ocean Surveillance Center
NELC	Naval Electronics Laboratory Center (became NOSC in 1977 and NCCOSC RDT&E Div [NRaD] in 1992)
NOSC	Naval Ocean Systems Center
PA	Power Amplifier
RADHAZ	Radiation Hazard
RAN	Royal Australian Navy

SAOA	Standard Association of Australia
TELCOM	Telecommunications Command
VLF	Very Low Frequency

APPENDIX A

EXPECTED FIELDS VOLTAGES AND CURRENTS

The electrically short top-loaded monopole is as old as radio itself. This type of monopole can be thought of as a giant capacitor with some inductance in the up-lead. The antenna, which is tuned by a giant inductor (helix) located in the helix house, can be characterized by three parameters: (1) effective height, (2) static capacitance, and (3) self resonant frequency. These parameters are to first-order frequency independent. Other frequency-dependent parameters, such as base reactance, radiation resistance, etc., can be derived from them.

The other important factor is radiation efficiency, which is a function of frequency. The losses for such an antenna occur in many locations. There are direct losses from the antenna current flow in the tuning elements, the active antenna structure, antenna insulators, and the antenna ground system. Induced currents also causing losses, flow in the earth, the helix house structure, and in the inactive portions of the antenna structure. These losses have many terms with different frequency variations. The composite of these losses often increases approximately linearly with frequency. Since the radiation resistance increases with frequency squared, the antenna efficiency increases with frequency.

Given the three frequency-independent parameters and efficiency, the operating parameters such as base impedance, bandwidth, voltages, currents, radiated power, etc. can be determined.

Table A1 contains the parameters for the VLF HEH. The 5- and 6-panel characteristics were obtained from HNCD (1967) and the 4-panel characteristics were estimated. The first three rows are the frequency independent parameters. (Note that these parameters are estimates only for approximating near field magnitudes.)

Table A1. VLF Harold E Holt estimated parameters. 19.8 kHz.

	6 Panel	5 Panel	4 Panel
he (m)	187	185	183
Co (nF)	162.6	143.4	123.0
fo (kHz)	34.2	35.0	36.0
eff %	82.4	79.6	77.7
Xo	48.8	55.4	65.4
Xb	33.3	38.8	45.6
Rr	0.240	0.235	0.230
Ras	0.293	0.295	0.297

where
he = effective height
Co = static capacitance
fo = self resonance
Xo = reactance of static capacitance
Xb = reactance at antenna base
Rr = radiation resistance
Ras = antenna system resistance

Given the parameters of table A1, and the required radiated power, the voltages and currents have been derived and are given in table A2.

Table A2. Voltages and currents for operating modes at VLF HEH 19.8 kHz.

	6 Panel	5 Panel	4 Panel
Prad (MW)	1.63 (Max Power)	1.0 (Full Power)	1.0
Ias (Amps)	2600	2062	2089
Vb (kV)	86.6	80.0	95.3
Vt (kV)	126.9	114.2	136.6
Eavg (v/m)	678	617	734
Ef (V/m)	1634	1501	1798

where Prad = radiated power
Ias = antenna system current
Vb = base voltage
Vt = top-load voltage

ELECTRIC FIELDS

Coarse estimates of the expected fields are derived from voltages, currents, and antenna dimensions. The average electric field under the topload is estimated by:

Eavg = Vt/he,

The maximum electric field under the feeders can be estimated by

Ef = Vb/h * 2/ln(2h/aeqe) ,

where *h* = the height of the feeder

aeqe = equivalent radius of the 4-wire cage.

The value of these estimates has been included in the last two rows of table A2. These estimates are high because they do not include the shielding effect of the towers, guy-wires, and transmitter building.

The towers that hold up the top-load are all grounded and have grounded guy wires (figure 4 in the main text). The towers and guy wires shield the area around the tower bases so that the average field in these areas is low. The area inside of the towers is shielded and the electric field in these areas is low.

Outside the tower, the fields will be higher. This area is partially shielded by the guy wires, so near the base the fields outside the tower are low. Higher up the tower, the electric fields outside the tower will be greater because of increasing proximity to the active top-load, and the presence of fewer shielding guy wires. The maximum electric fields will be outside the tower in the tower top area above the top guy wire. For a tower with an active panel attached, these fields are several kV/m.

From the above, it is clear that there are areas on the ground around the transmitter building and at the tower tops where the electric fields can exceed the field limit given in the standard.

MAGNETIC FIELDS

The magnetic field in the vicinity of a current carrying conductor can be calculated by

$$H = I/(2*\mathrm{Pi}*r),$$

where H = magnetic field (A/m)

I = current (A)

r = distance to conductor.

Note that this field is doubled if the current is parallel to a conducting ground plane and the measurement point near the ground plane.

The maximum current in the HEH VLF system on 19.8 kHz is 2600 A. To exceed the limit given in the IEEE standard of 167 A/m, one would have to be within 5 meters of a conductor carrying this current. There is no region normally accessible while operating where this is possible. The roof area near the bushings and under the 4-wire cage bus could have fields of this magnitude, but is not accessed while operating.

The large inductors and proximity of helix house walls considerably complicates the magnetic field calculation. For this reason, all regions accessed by personnel (including the active helix house observation areas and the inactive helix house) need to be checked for magnetic fields as well as electric fields..

The magnetic field estimated under the feeders is given by

$$H = If/(2*\mathrm{Pi}*h),$$

where If = feeder current

h = feeder height (approximately 30 m).

The total current divides about equally between the feeders. The worst case (highest H field) is the 4-panel mode when the feeders carry 522 A. For this case, the magnetic field expected on the ground is about 6 A/m, still well under the limit.

The magnetic field away from T0, but under the top-load, is due to the total antenna current in the vertical up leads, and the currents in the top-loads. The inner ring of towers is located at a radius of 2124 feet from T0. The estimated magnetic field from the vertical currents at that distance would be 640 mA/m.

At the tower top, the magnetic field from the vertical currents is augmented by the current flowing in the top-load wires nearest the tower. At maximum power, this current is estimated to be the equivalent of 72 A in the wires on each side of a center tower. These wires are located about 200 ft from the tower top. The additional field above that caused by the vertical currents is estimated to be 377 mA/m. The estimated maximum possible magnetic field is the sum of fields, or 980 mA/m.

The magnetic fields on an outer tower will be considerably less because they are farther from the vertical current source, and the currents near the end of the panel are low.

From the above discussion, it is clear that magnetic fields will not approach the allowable limit anywhere outside of the transmitter building.

APPENDIX B

CALIBRATION DATA

ELECTRIC FIELD MEASUREMENTS

The E-field strength meter is portable and can be carried up the towers for measurements. The E-field meter is extended on a broom handle away from the observer. Readings are taken from a large meter on the front of the device. This meter was calibrated at the NRaD parallel plate calibration facility in the model shop (figure B1). The calibration data for the parallel plate facility and the NRaD E-field meter are given in figures B2 to B4.

MAGNETIC FIELD MEASUREMENTS

Magnetic fields were measured by using the blue multiturn loop supplied by Watt Engineering. For these measurements, the loop is connected to an HP digital multimeter, which has an accuracy better than 1% at VLF. The multimeter will be shielded in a custom-made copper box and grounded to the coax to eliminate E-field pickup. This setup was calibrated by using the NRaD Helmholtz calibration coil facility, also supplied by Watt Engineering (figures B5 and B6). The calibration data for the Helmholtz coil and the Blue Loop are given in figures B7 to B9.

An electric monopole such as the HEH antenna has very large electric fields in the vicinity of the antenna. When making measurements of H field in the area of a large electric field, care must be taken to eliminate any electric field pickup. We use a well-shielded loop antenna with double-shielded coax. The loop shield, the coax shield, and the meter shield are solidly connected together.

BODY CURRENTS

The body currents were measured by using the digital multimeter in the shielded box. The meter was operated in the current mode. The meter was connected in series between the person and the object touched. We also made body currents with two in-line meters supplied by NAMRL.

CABLE CURRENTS

The currents in cables were measured by using the large (8-inch id) Genestron clamp on current probe and the smaller (2 1/2-inch id) Fluke clamp-on current probe. Both current probes require a 50-ohm termination. The termination is attached immediately at the output of the current probe to help eliminate any E-field pickup. The same HP Digital multimeter used for the H-field measurements will be used for these measurements. The meter will be shielded and grounded to the coax to eliminate E-field pickup. The calibration method is illustrated in figure B10. The calibration data for the Fluke and Genestron clamp on current probes are given in figures B11 to B17.

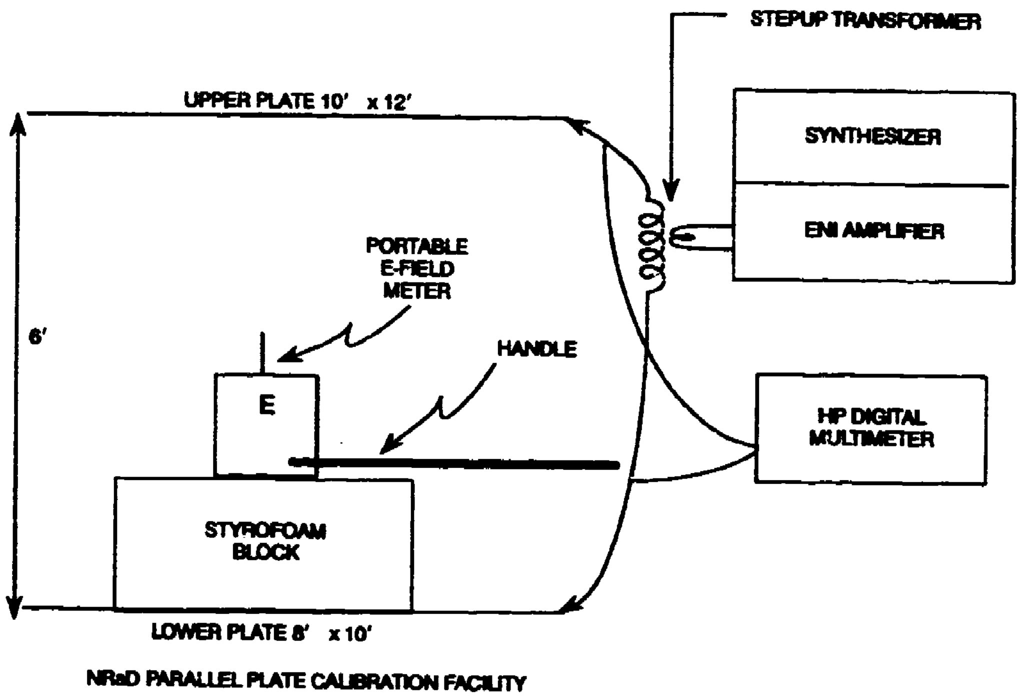

Figure B1. E-field calibration procedure.

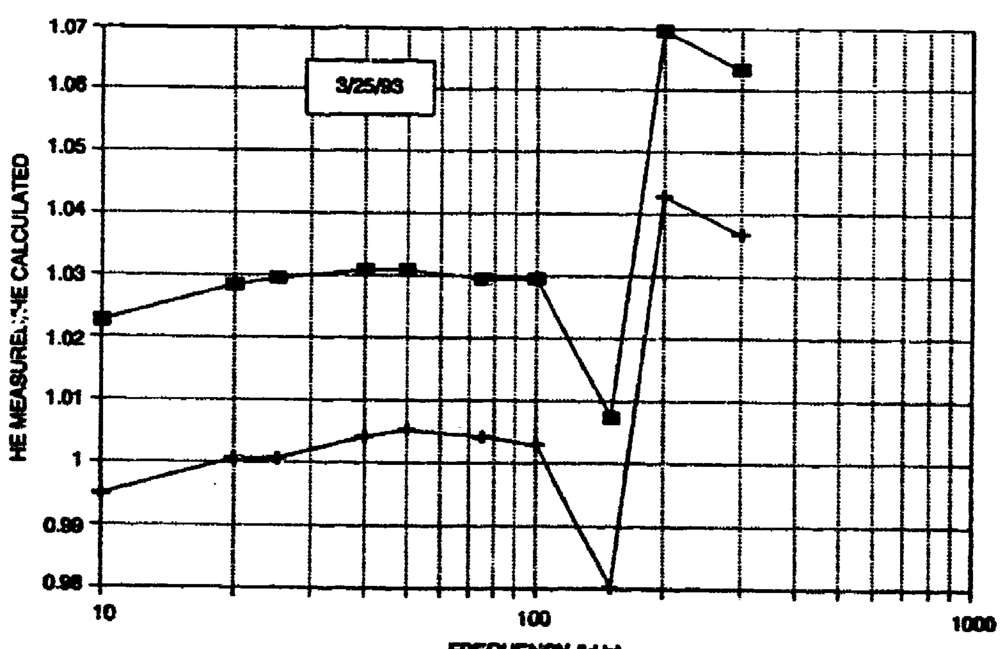

Figure B2. Parallel plate cal, 1-ft monopole HP3586C PA#65173+1124A probe.

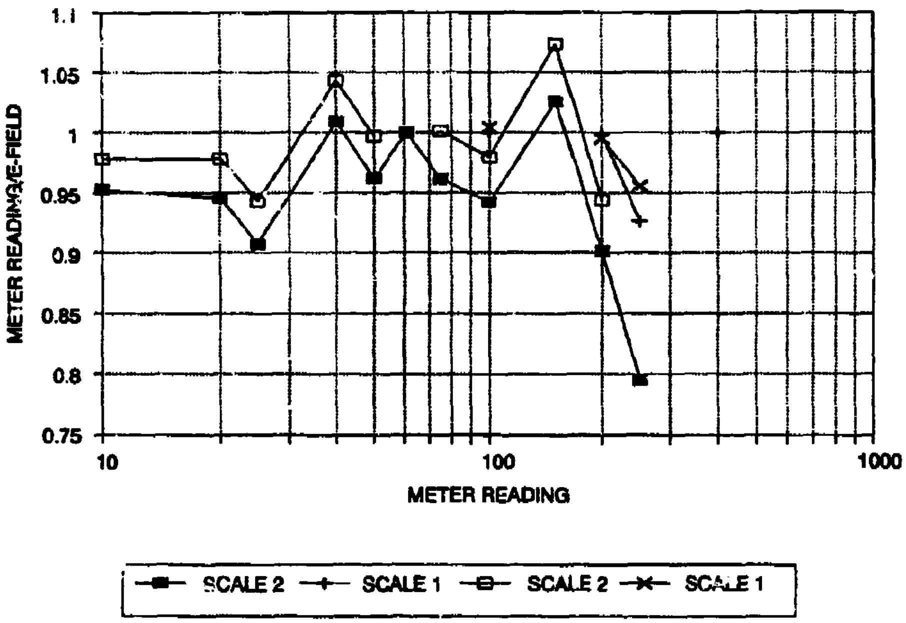

Figure B3. E-field meter calibration @ 19.8kHz
NRaD parallel plate facility 3/24/93.

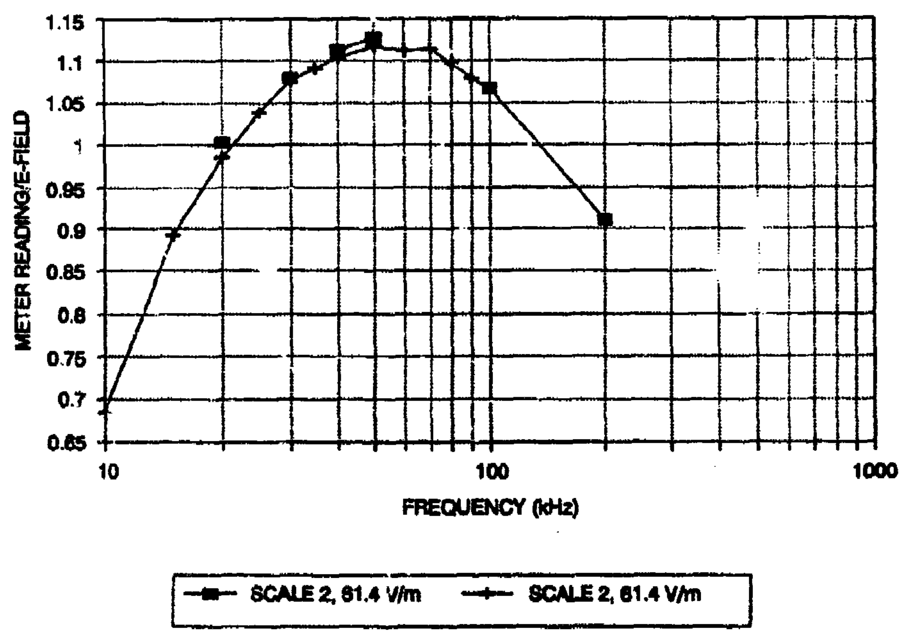

Figure B4. E-field meter calibration
NRaD parallel plate facility 3/24/93.

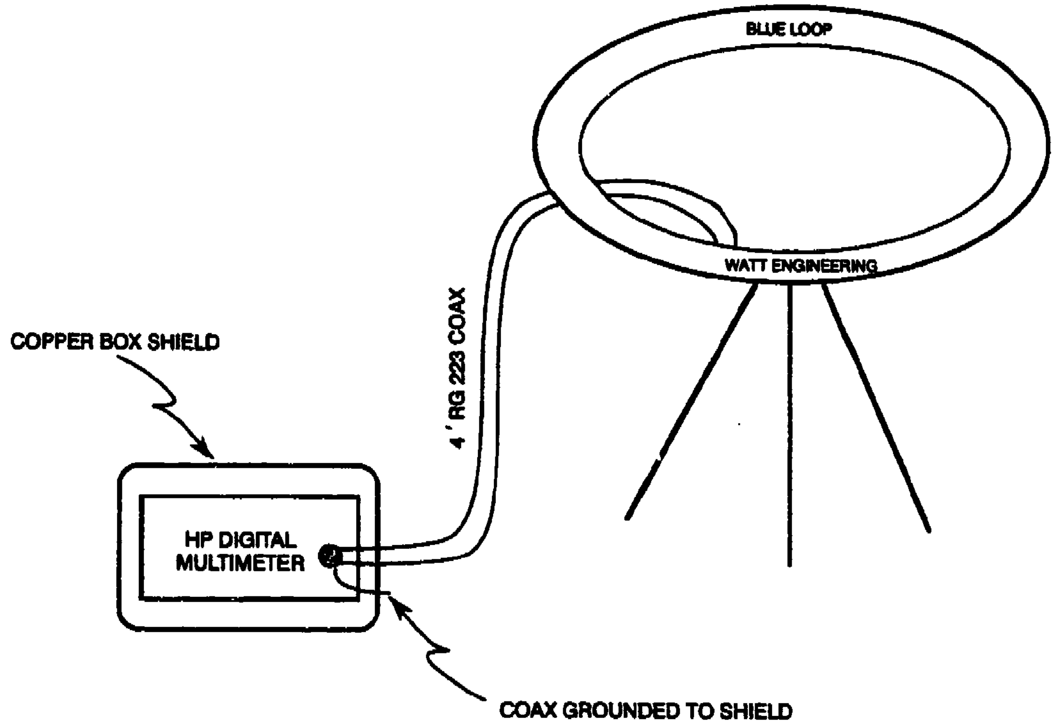

Figure B5. H-field measurement equipment.

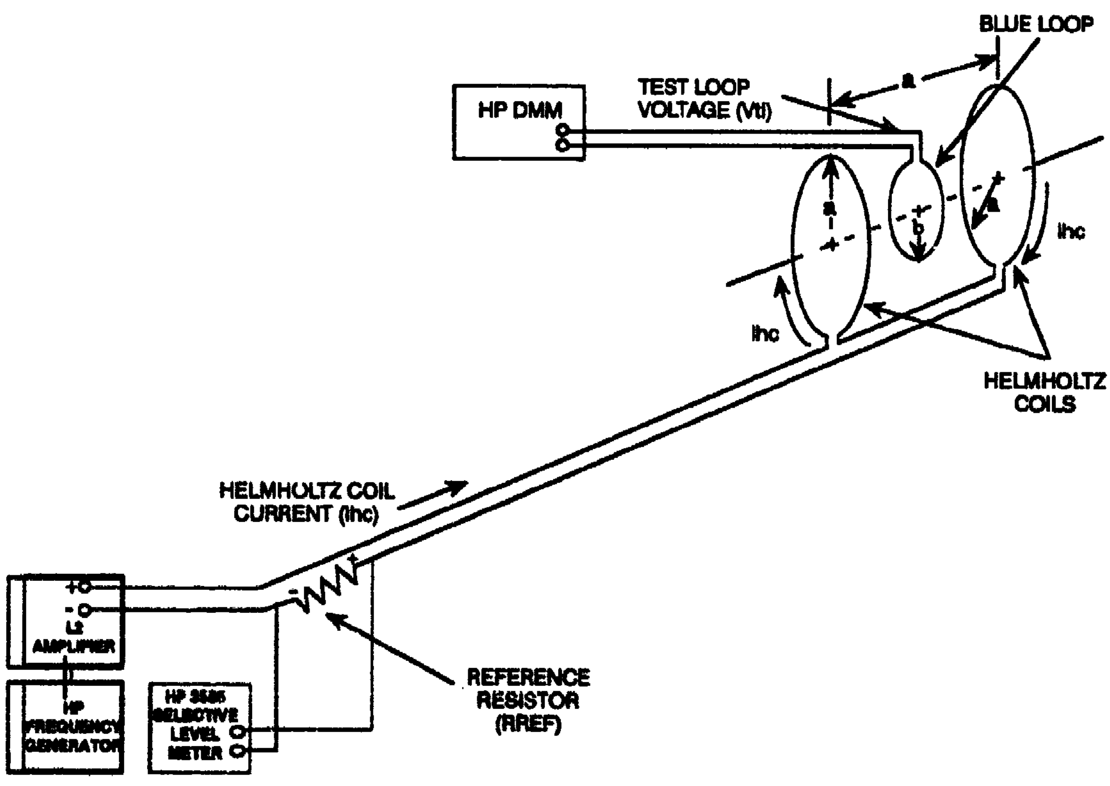

Figure B6. H-field calibration procedure.

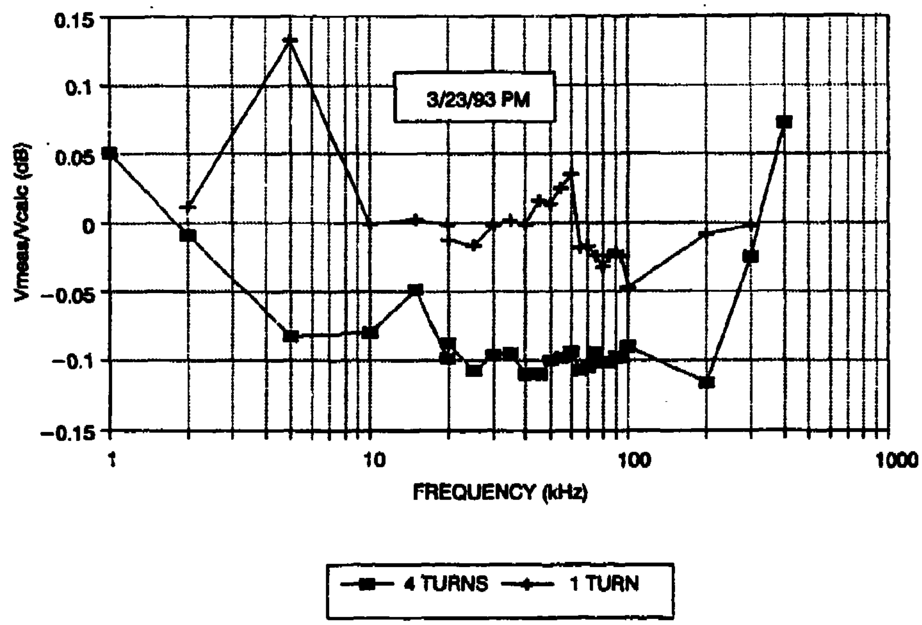

Figure B7. NRaD 1-meter Helmholtz coil calibration air core loop standard, A = 0.0491 m sq.

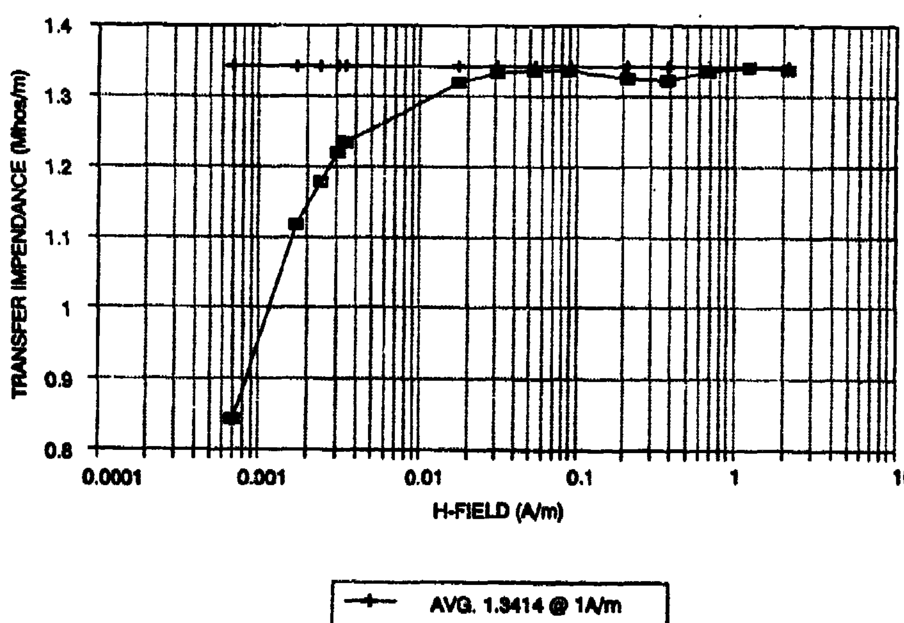

Figure B8. Calibration blue loop and DMM @ 19.8kHz 3/24/93 HP-3468 PA 84147 unterminated.

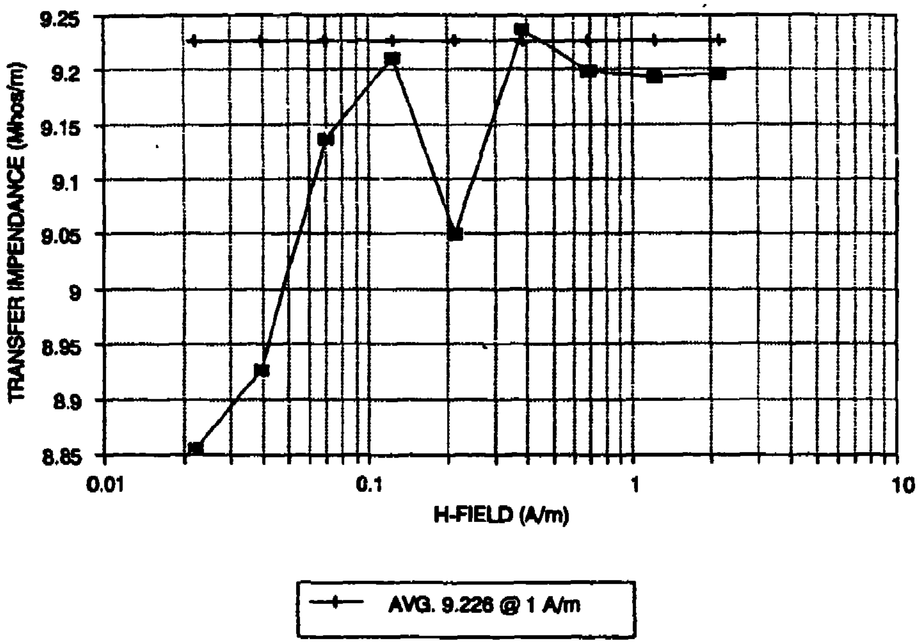

Figure B9. Calibration blue loop and DMM @ 19.8kHz 3/24/93 50-ohm termination HP-3468 PA 84147.

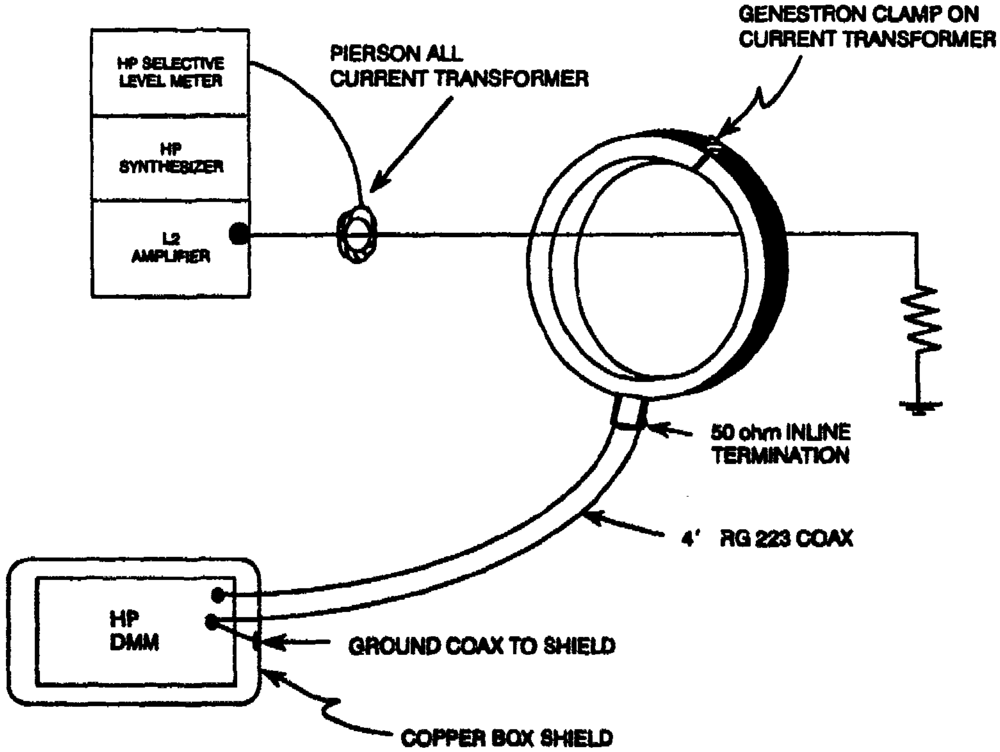

Figure B10. Body current measurement system and calibration procedure.

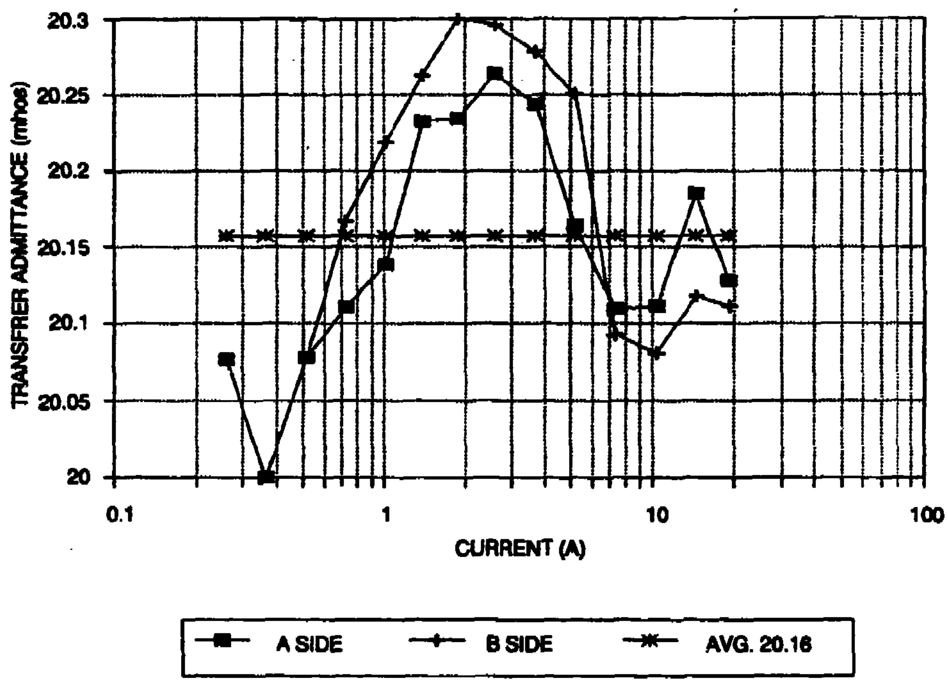

Figure B11. Clamp on calibration, 3/25/93
50-ohm termination HP-3468 PA 97873.

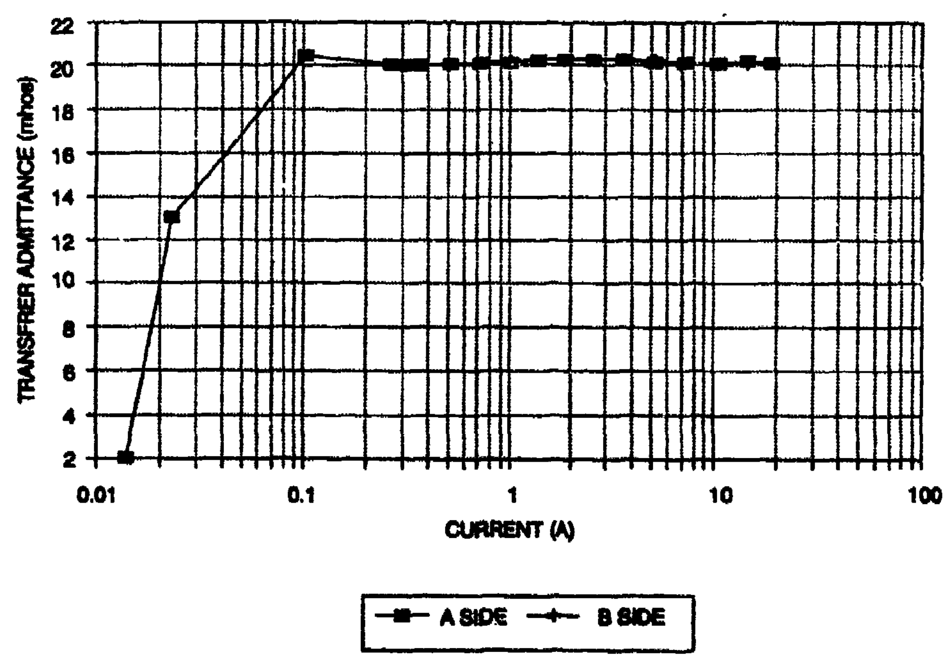

Figure B12. Fluke clamp on calibration, 3/25/93
50-ohm termination HP-3468 PA 97873.

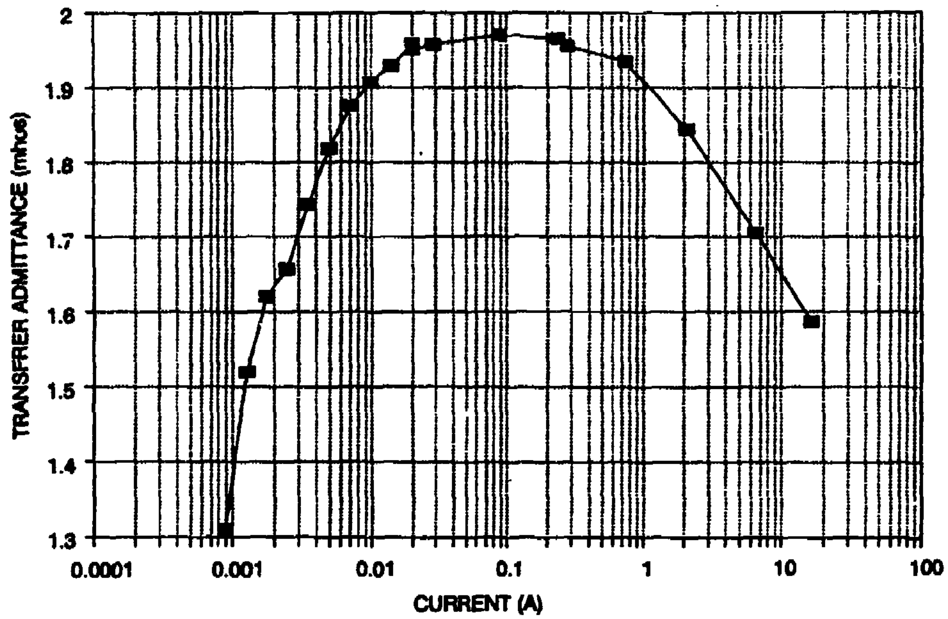

Figure B13. Genestron clamp on calibration, 3/25/93
50-ohm termination HP-3468 PA 97873.

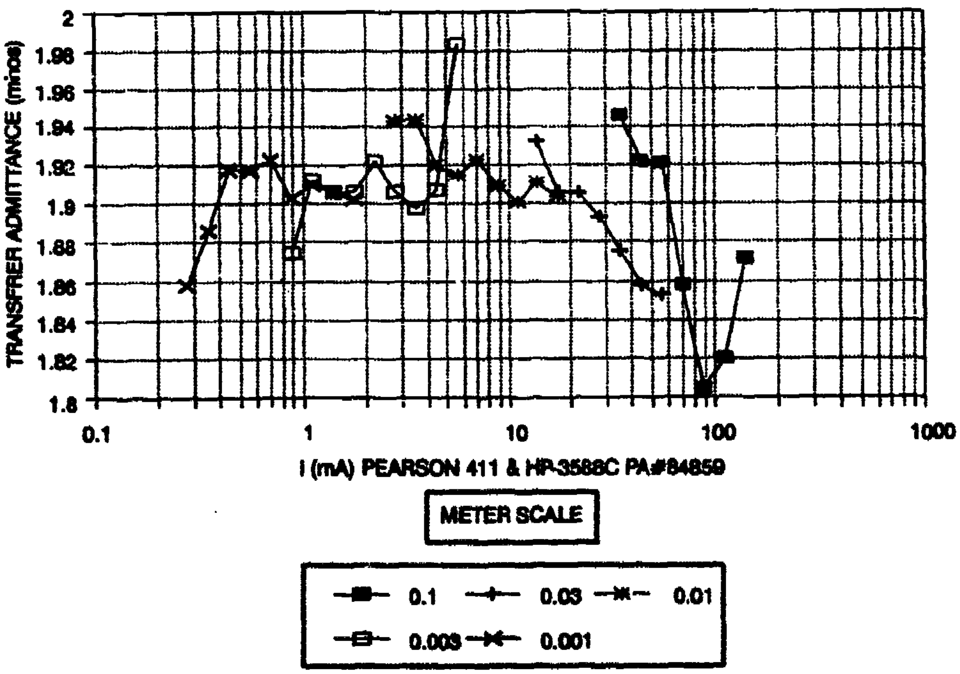

Figure B14. Genestron current probe calibration
50 ohm, HP-403A RF voltmeter, 4/13/93.

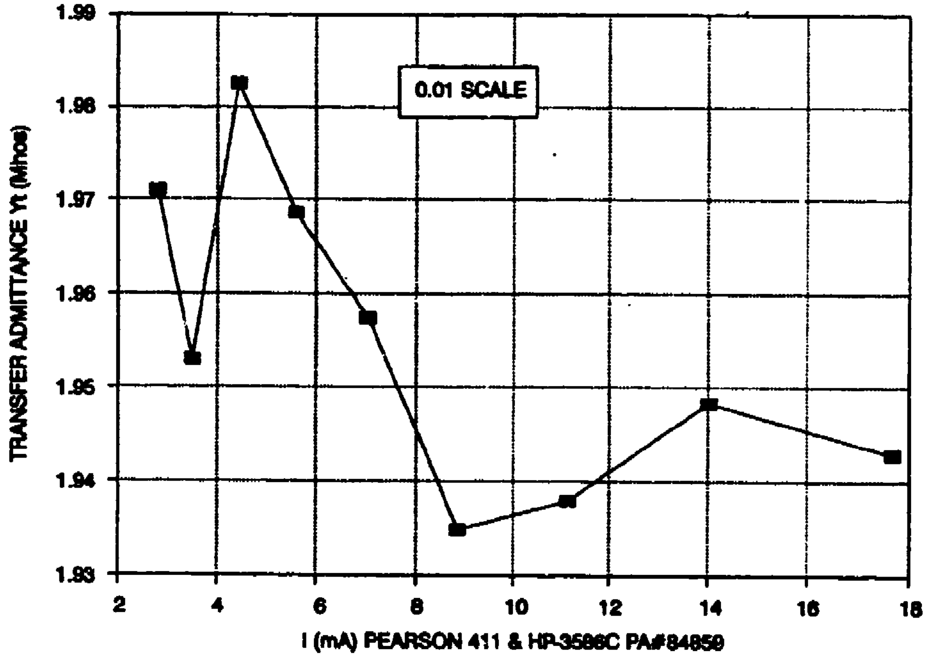

Figure B15. Genestron current probe calibration
50 ohm, HP-403A RF voltmeter, 4/14/93.

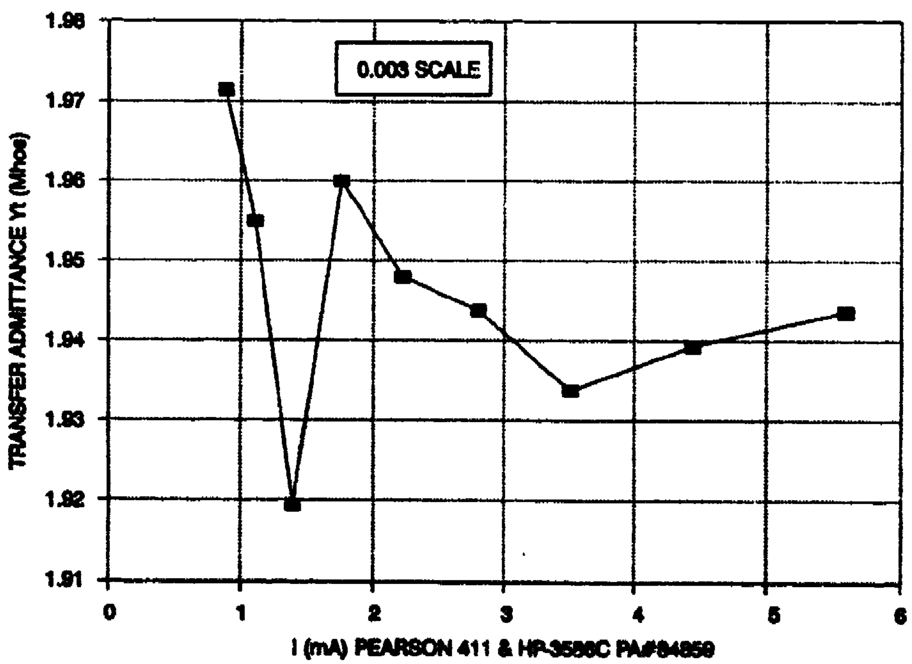

Figure B16. Genestron current probe calibration
50 ohm, HP-403A RF voltmeter, 4/14/93.

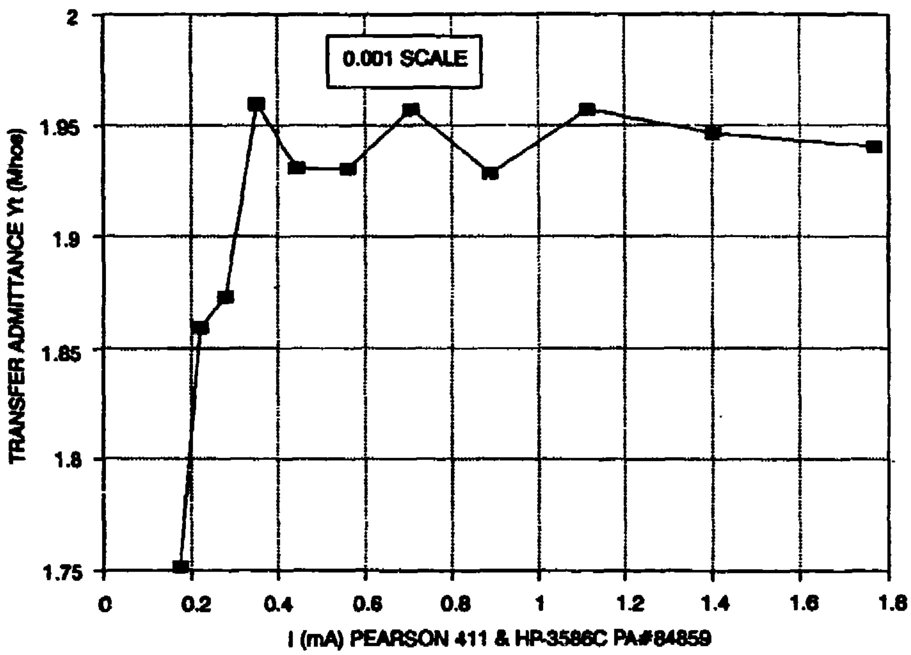

Figure B17. Genestron current probe calibration
50 ohm, HP-403A RF voltmeter, 4/14/93.

APPENDIX C

FUSING CURRENTS FOR HOIST AND TROLLEY LINE CABLES

The hoist system used by the riggers to carry materials, tools, and equipment up the tower for maintenance is illustrated in figure 4 (main body of report). There are two cables used in the hoist system. The larger cable is actually used to hoist the cage carrying equipment, etc., and has a nominal diameter of 0.6 inch. The smaller cable, called the trolley line, has a nominal diameter of 0.35 inch.

A one-foot-long sample of each of these cables was obtained for testing. Tests were done at the Forrestport, NY, high-voltage test facility. The makeup of these cables is illustrated in figures C1 and C2. The hoist cable is made up of 0.030-inch wire strands. The trolley cable uses both 0.020- and 0.010-inch strands in its makeup. However, only the 0.020-inch strands are on the outside.

Fusing currents for the individual strands were measured by using a 60-Hz source and a LF source operating at a nominal frequency of 41 kHz. The test procedure was to place the sample in a test jig and raise the current (60 Hz or LF) through the sample until the sample fused. For each test, three or more samples were fused. The results are given in table C1.

From table C1, it is seen that the 60 Hz and LF fusing currents are essentially the same. The fusing current for the 0.020-inch strands in about 11 A. The fusing current for the 0.030-inch strands is 15 A or more.

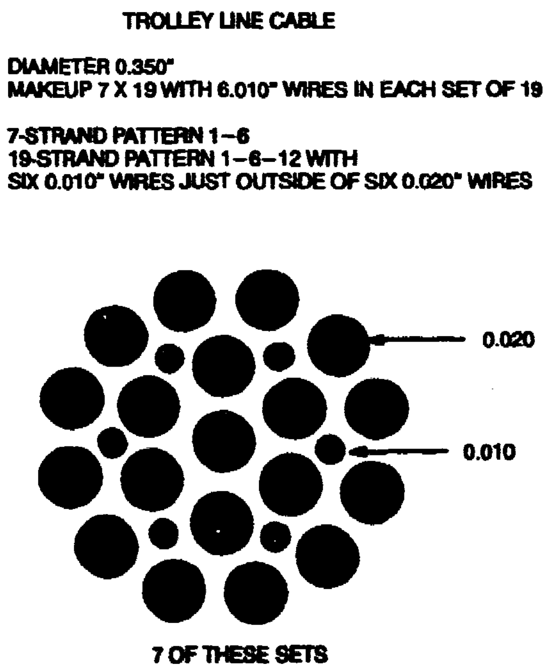

Figure C1. HEH trolley cable makeup.

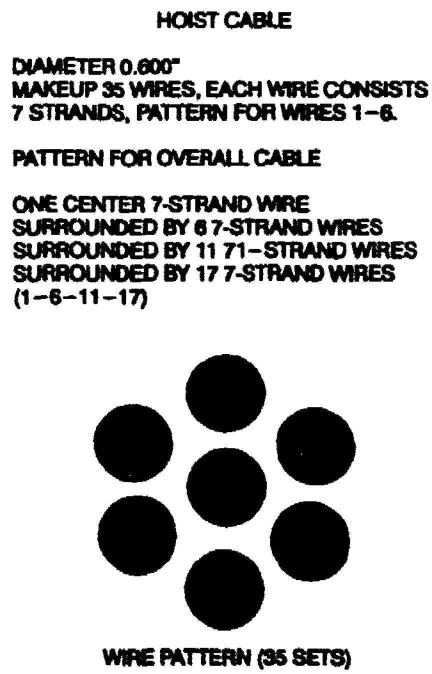

Figure C2. Hoist cable makeup.

Table C1. Fusing currents for hoist system cable strands.

Small Cable			
0.010 Strand			
60 Hz		40.950 kHz	
I	V	I	V
3.7 A	34.5 V	3.8 A	11.0 kV
3.9 A	31.7 V	3.9 A	11.5 kV
3.4 A	39.2 V	3.9 A	11.6 kV
0.020 Strand			
60 Hz		40.950 kHz	
I	V	I	V
9.4 A	21.6 V	12.1 A	37.1 kV
9.6 A	20.4 V	12.1 A	37.0 kV
10.2 A	20.1 V	10.8 A	33.1 kV
		10.4 A	31.6 kV
		11.8 A	36.5 kV
		AVG 11.4 A	

Large Cable			
0.029 Strand			
60 Hz		40.950 kHz	
I	V	I	V
15.4 A	17.0 V	15.8 A	48.7 kV
14.3 A	16.0 V	16.1 A	49.5 kV
14.2 A	19.0 V	15.6 A	47.9 kV
		AVG 15.8 A	
0.032 Strand			
60 Hz		40.950 kHz	
I	V	I	V
19.0 A	16.0 V	21.1 A	65.1 kV
17.2 A	18.0 V	20.2 A	62.1 kV
19.4 A	16.0 V	20.7 A	63.8 kV
		AVG 20.7 A	

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13. ABSTRACT *(Maximum 200 words)*

This document details the radiation hazard (RADHAZ) measurements made at the very-low-frequency (VLF) Harold E. Holt (HEH) transmitting facility by personnel from U.S. Naval Command, Control and Ocean Surveillance Center (NCCOSC), Research, Development, Test and Evaluation Division (RDT&E Div.), the U.S. Naval Aerospace Medical Research Laboratory (NAMRL), the Australian Defence Force (ADF), and the Royal Australian Navy (RAN). The measurements were made to determine if hazardous levels of electromagnetic fields existed in locations normally accessed by personnel. NAMRL and ADF personnel were primarily responsible for the measurements on the ground and in and around the transmitter building; NRaD personnel were primarily responsible for measurements on the towers.

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