Evaluation of Radiofrequency Radiation Exposures at an Atomic Time Radio Station

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Report No. 2011-0097-3200
December 2013

U.S. Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

Contents

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The cover photo is a close-up image of sorbent tubes, which are used by the HHE Program to measure airborne exposures. This photo is an artistic representation that may not be related to this Health Hazard Evaluation. Photo by NIOSH.

Highlights of this Evaluation

The Health Hazard Evaluation Program received a request from a federal research institution. Health and safety managers submitted the request because of concern about possible radiofrequency exposures at the research institution's atomic time radio station in Hawai'i.

What We Did

- We evaluated radiofrequency electric and magnetic field exposures at the radio station in January 2012.

What We Found

- Electric and magnetic field strengths measured on the roof, in the office, and in the transmission room of the radio station building were below the OELs and action levels.
- Electric and magnetic field strengths around the 10- and 15-megahertz antennas were below exposure limits and action levels inside the pickup truck that tows a mower used on the antenna field.
- Electric and magnetic field strengths exceeded action levels near the antennas, an area called the antenna field.
- Electric and magnetic field strengths exceeded exposure limits near the fences surrounding the 5-, 10-, and 15-megahertz antennas.
- Magnetic field strengths exceeded exposure limits about halfway up the weather station tower.
- Magnetic field strengths near unpowered 10- and 15-megahertz antennas exceeded exposure limits.
- During activities involving primary or backup antennas that were powered off, or when servicing the weather station, employees could be overexposed to magnetic fields induced from nearby transmitting antennas.

We evaluated radiofrequency exposures at an atomic time radio station. Electric and magnetic field strengths exceeded action levels and exposure limits in certain areas of the antenna field, but not inside, just outside, or on the roof of the radio station building. We measured electric and magnetic field strengths inside the pickup truck that tows a mower used on the antenna field; all were below action levels. We recommend a comprehensive radiofrequency safety program.

What the Employer Can Do

- Start a comprehensive radiofrequency safety program.
- Install caution signs to identify areas where exposure limits could be exceeded. Tell employees not to enter these areas unless the antenna has been turned off or they are inside the pickup truck while mowing.
- Reduce power to a primary antenna before working on the standby antenna of the same frequency or vice versa.

What the Employer Can Do (continued)

- Reduce power to the 5-megahertz antenna before servicing the weather station.
- Train employees on the potential hazards associated with radiofrequency exposure.

What the Employee Can Do

- Learn about radiofrequency radiation hazards and the purpose of signs and other controls to prevent overexposures to radiofrequency radiation.
- Report health and safety concerns to your manager.
- Share ideas on ways to improve the radiofrequency safety program with the safety officer.

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Abbreviations

A/m	Amps per meter
ACGIH®	American Conference of Governmental Industrial Hygienists
CFR	Code of Federal Regulations
FCC	Federal Communications Commission
GHz	Gigahertz
GPS	Global positioning system
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
kHz	Kilohertz
MHz	Megahertz
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
RF	Radiofrequency (30 kHz to 300 GHz)
RMS	Root-mean-square
TLV®	Threshold limit value
V/m	Volts per meter
WEEL	Workplace environmental exposure level

Introduction

The Health Hazard Evaluation Program received a request from a federal research institute. The request concerned potential employee exposures to radiofrequency (RF) radiation at the institute's atomic time radio station in Hawai'i. The purpose of the evaluation was to assess RF exposures at the radio station from the 2.5-, 5-, 10-, and 15-megahertz (MHz) antennas (Figure 1).

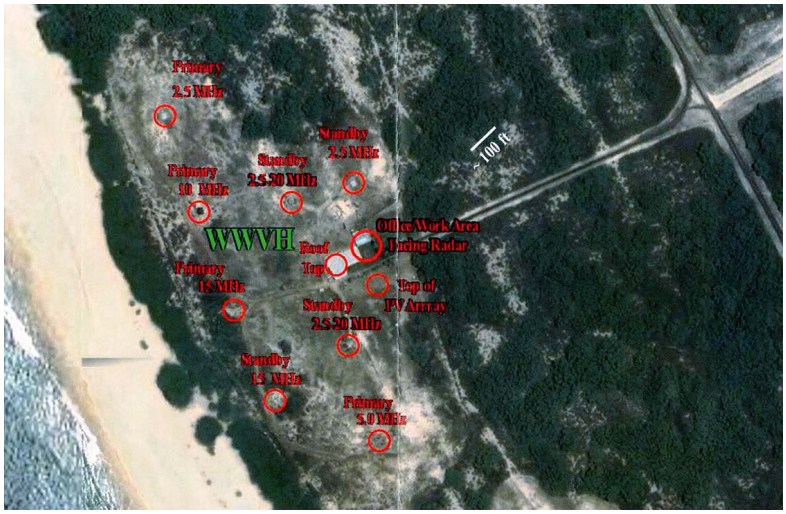

Figure 1. Aerial view of the radio station site. NIST Photo. Reprinted with permission.

Four employees worked at the radio station during our evaluation. The radio station broadcasts time announcements, standard time intervals, standard frequencies, geophysical alerts, marine storm warnings, and global positioning system (GPS) status reports. The station radiated 5 kilowatts on a 2.5-MHz antenna array and 10 kilowatts on 5-, 10-, and 15-MHz antenna arrays. Each frequency was broadcast from a separate transmitter. Additionally, a weather station was on top of a 45-foot tower [NIST 2012]. Most of the antennas were between the radio station building and the beach. For this evaluation we refer to this area as the antenna field.

Methods

We used a factory-calibrated Narda EHP-200 electric and magnetic field analyzer capable of measuring RF radiation propagated as electric and magnetic fields at frequencies between 9 and 30 MHz. The analyzer was connected to an isotropic probe capable of measuring field strengths in the X, Y, and Z directions at the same time. Because the human body can alter electric and magnetic fields, the probe and analyzer were connected to a laptop computer with fiber optic cable to minimize disturbances.

The probe was placed on a fiberglass tripod at groin height (about 3 feet) to collect most measurements (Figure 2). We took some additional measurements at head height (about 5.5 feet) and chest height (about 4 feet) to obtain data for spatial averaging across the human body as required by most RF standards. Most of our measurements were collected at groin height because we assumed that the groin height measurements would be about the same or higher than measurements collected at other heights. The measurements were collected around the 2.5-, 5-,

Figure 2. A Narda RF field analyzer measuring RF electric and magnetic fields near the primary 2.5-MHz antenna. Photo by NIOSH.

10-, and 15-MHz antennas as well as areas on the inside, outside, and on the roof of the radio station building.

Field strengths were recorded over 30 seconds and root-mean-square (RMS) values calculated. RMS is a statistical measure of the magnitude of a varying quantity. This calculation was performed automatically by the instrument software. For the majority of our measurements, we used 30-second averaging times instead of the 6-minute averaging times specified by most standards. In this evaluation a shorter averaging time could be used because the electric and magnetic fields at a stationary position were generally constant.

Neither the Occupational Safety and Health Administration (OSHA) nor the National Institute for Occupational Safety and Health (NIOSH) has occupational exposure limits (OELs) for RF electric and magnetic fields. However, OELs for electric and magnetic field strengths at the frequencies used at the radio station have been recommended by several professional organizations (Appendix A, Tables A1 and A2). According to the radiofrequency safety program guidelines established by the Institute of Electrical and Electronics Engineers (IEEE), reference levels for uncontrolled or general public exposure should be regarded as "action levels" for occupational settings [IEEE 2005a]. These levels are summarized in Tables A1 and A2 of Appendix A. In this report, we compared field strength measurements to the most conservative OELs and action levels. The most conservative OELs were set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The most conservative action levels were also set by ICNIRP with the exception of electric field strengths at 15-MHz, in which case, the American Conference of Governmental Industrial Hygienists (ACGIH) action level is most conservative (Appendix A, Table A1).

Because the radio station broadcasted in multiple frequencies, we performed a mixture analysis for electric and magnetic field strengths (Appendix B, Tables B13 and B14) as described in Annex D.2 of IEEE Standard C95.1-2005 [IEEE 2005b]. Briefly, we obtained the ratio of each squared frequency-specific field strength to the square of its frequency-specific OEL. We then summed the ratios for all frequencies. To comply with OELs, the sum of the ratios should not exceed 1 (unity). This formula was also used after spatially averaging the field strengths in the locations where we collected head, chest, and groin height

measurements to comply with the mixture analysis and spatial averaging elements of the OELs (Appendix B, Tables B13 and B14).

Results and Discussion

The electric and magnetic field strength measurements are provided in Tables B1–B14 of Appendix B. Because all overexposures were the result of the predominant frequency, we present the field strengths for only the predominant frequencies in Tables B1–B12 of Appendix B.

Several measurements taken in the antenna field were above OELs or action levels (Appendix B, Tables B1–B10). For example, the following measurements exceeded OELs:

- electric and magnetic fields at groin height north of the 15-MHz standby antenna (Appendix B, Tables B1 and B2)
- electric and magnetic fields at groin height 30 feet from the 10-MHz antenna (Appendix B, Tables B3 and B4).
- magnetic fields at a height of about 16 feet at the weather station tower (Appendix B, Tables B9 and B10)

Measurements exceeding action levels included the following:

- electric and magnetic fields at groin height 15 feet from the 5-MHz antenna (Appendix B, Tables B5 and B6)
- electric and magnetic fields at groin height at the fence around the 2.5-MHz standby antenna (Appendix B, Tables B7 and B8).
- electric fields at a height of about 16 feet at the weather station tower (Appendix B, Tables B9 and B10)

Electric and magnetic field strengths were below the OELs and action levels in the cab of the pickup as well as on the roof, in the office, and in the transmission room of the radio station building (Appendix B, Tables B1–B4, B9–B12).

Spatial averaging of field strength measurements is required by most RF standards (Appendix A). Electric and magnetic fields should be averaged over an area equivalent to the vertical cross section of the human body. Electric and magnetic field strengths 30 feet, 130° southeast of the primary 15-MHz antenna were among the highest measured. Field strengths were collected here for spatially averaged exposure estimations (Tables B13 and B14). Compared to the groin height measurements at this location, spatial averaging resulted in a lower estimate of exposure for electric fields (Appendix B, Table B13) and a higher estimate of exposure for magnetic fields (Appendix B, Table B14).

Our measurements presented in Appendix B suggest that employees could potentially be overexposed to electric and magnetic fields while in the antenna field, however employees did not typically spend much time in this area. Most of the time, employees worked in

the radio station building. By talking with employees, we identified the following routine but infrequent activities in the antenna field that could result in electric and magnetic field overexposures:

- Cleaning, repairing, and painting antennas
- Maintaining the weather station
- Mowing the antenna field

When employees clean, repair, paint, or perform other work around an antenna, the antenna is powered off using lockout/tagout procedures. If the antenna being serviced is a primary antenna, the backup is turned on to maintain the transmission for that frequency.

To prepare the primary 10-MHz antenna for these activities, the backup 10-MHz antenna was powered on and the primary 10-MHz antenna was powered off. In an attempt to eliminate current induced in the primary 10-MHz antenna by the backup, the primary 10-MHz antenna was grounded with a grounding strap placed between the antenna and the tuning box.
To prepare the backup 15-MHz antenna for these activities a grounding strap was placed between the backup antenna and the tuning box. The primary 15-MHZ antenna continued to broadcast as usual.

We measured electric and magnetic field strengths within a few inches of the powered down antennas (Tables 1 and 2). The only electric field measurement location that exceeded an action level (but not an OEL) was at the 15-MHz standby antenna nearest the building (Table 1).

Table 1. Electric field measurements* during simulated antenna maintenance, in V/m

Location	Measurement height (feet)	Frequency (MHz)			
		2.5	5	10	15
At the base of the standby 10-MHz antenna (off and grounded at tuning box)	1	6.73	15	16.2	7.47
At the grounding wire for the standby 10-MHz antenna	1	8.54	26.8	22.4	9.78
At the grounded tuning box for the standby 10-MHz antenna	1	5.38	6.7	11	16.2
At the base of the standby 15-MHz antenna nearest beach (off and grounded at the transmitter)	1	5.13	16.1	5.55	10.77
Standby 15-MHz antenna nearest building (off and grounded at the transmitter)	10	6.71	21.76	13.66	<u>37</u>
ICNIRP OEL (reference levels for occupational exposure)		244	122	61	61
ICNIRP action level (reference levels for general public exposure)		55	40	28	28

V/m = volts per meter

*30-second averaging time unless otherwise noted

Measurements exceeding action levels are underlined.

Magnetic field strengths exceeded the OELs at the base of the standby 10-MHz antenna and about 10 feet high on the standby 15-MHz antenna (Table 2). Note that the 5-MHz magnetic field strength was > 90% of the OEL and the 10-MHz magnetic field strength was > 120% of the OEL at the base of the standby 10-MHz antenna (Table 2). Even if the primary 10-MHz antenna was transmitting at 50% power (as a possible control measure), the combined magnetic field strengths from the 5- and 10-MHz frequencies could still exceed the OEL at the base of the standby 10-MHz antenna. Although reducing power to a transmitting antenna is a viable control to lessen induced RF fields in an unpowered antenna of the same frequency, field strength measurements would be necessary to verify that the power reduction level results in combined field strengths below the OEL.

Table 2. Magnetic field measurements* during simulated antenna maintenance, in A/m

Location	Measurement height (feet)	Frequency (MHz)			
		2.5	5	10	15
At the base of the standby 10-MHz antenna (off and grounded at tuning box)	1	0.15	<u>0.31</u>	**0.198**	0.052
At the grounded tuning box for the standby 10-MHz antenna	1	0.021	0.025	0.02	0.024
At the base of the standby 15-MHz antenna nearest beach (off and grounded at the transmitter)	1	0.021	0.06	0.019	0.049
Standby 15-MHz antenna nearest building (off and grounded at the transmitter)	10	0.012	0.043	0.03	**0.17**
ICNIRP OEL (reference levels for occupational exposure)		0.64	0.32	0.16	0.16
ICNIRP action level (reference levels for general public exposure)		0.3	0.15	0.073	0.073

A/m = amps per meter

*30-second averaging time unless otherwise noted

Measurements exceeding occupational exposure limits are bolded.

Measurements exceeding action levels are underlined.

Employees occasionally serviced the weather station near the top of a tower in the antenna field. Prior to our evaluation, employees reached the weather station by climbing the tower, but currently use a bucket or scissor lift. We measured increasing electric and magnetic field exposures with increasing height up the weather station tower (Tables 3 and 4). Electric field strengths exceeded action levels at a height of about 8 feet and above (Table 3). Magnetic field strengths at the same location exceeded action levels at a height from about 3 to 8 feet and exceeded OELs above 16 feet (Table 4).

Table 3. Electric field measurements* at the weather station tower in V/m (5- and 10-MHz standby antennas on)

Location	Measurement height (feet)	Frequency (MHz)			
		2.5	5	10	15
Next to the weather station receiving antenna	about 3	1.26	11.7	2.49	3.14
1/3 of the way up the weather station antenna	about 8	4.6	<u>66</u>	10.2	20
1/2 of the way up the weather station antenna	about 16	5.98	<u>75.8</u>	9.2	10.4
ICNIRP OEL (reference levels for occupational exposure)		244	122	61	61
ICNIRP action level (reference levels for general public exposure)		55	40	28	28

*30-second averaging time unless otherwise noted

Measurements exceeding action levels are underlined.

Table 4. Magnetic field measurements* at the weather station tower in A/m (5- and 10-MHz standby antennas on)

Location	Measurement height (feet)	Frequency (MHz)			
		2.5	5	10	15
Next to the weather station receiving antenna	about 3	0.015	<u>0.16</u>	0.019	0.018
1/3 of the way up the weather station antenna	about 8	0.025	<u>0.27</u>	0.032	0.024
1/2 of the way up the weather station antenna	about 16	0.027	**0.35**	0.049	0.039
ICNIRP OEL (reference levels for occupational exposure)		0.64	0.32	0.16	0.16
ICNIRP action level (reference levels for general public exposure)		0.3	0.15	0.073	0.073

*30-second averaging time unless otherwise noted

Measurements exceeding occupational exposure limits are bolded.

Measurements exceeding action levels are underlined.

The electric and magnetic fields near the weather station tower and unpowered antennas were induced from nearby antennas and suggest that employees could be overexposed when working on the weather station or powered down antennas. When employees touch the weather station tower or the antennas (called coupling), electric currents induced in the structures can pass through their bodies (called induced body current). We did not measure induced body current in this evaluation, but these measurements are the best way of determining an employee's RF exposure due to coupling.

According to the employees, mowing accounts for the greatest proportion of time spent in the antenna field. Employees mowed the antenna field about twice per year by towing a mower behind a pickup truck. Smaller areas not accessible with the pickup truck such as the fenced areas surrounding the antennas were mowed with gas powered trimmers and push mowers. The antenna was powered off while employees worked in these fenced-in areas. When measured outside of the pickup truck (by the window), the electric and magnetic field strengths within 30 feet of these antennas exceeded OELs or action levels (Appendix B, Tables B1–B4). Our measurements inside the cab of the pickup truck (Tables 5 and 6) showed that the cab of the pickup truck reduced electric and magnetic field exposure to the occupants even when within 30 feet of a transmitting antenna.

Table 5. Electric field levels inside the pickup truck within 30 feet of the 10- or 15-MHz antenna in V/m

Location	Measurement height	Frequency (MHz)			
		2.5	5	10	15
Driving around the 10-MHz antennas for 2 minutes	Head (window)	0.82	0.58	4.81	0.68
Driving around the 15-MHz antennas for 2 minutes	Head (window)	0.56	0.57	0.66	3.8
ICNIRP OEL (reference levels for occupational exposure)		244	122	61	61
ICNIRP action level (reference levels for general public exposure)		55	40	28	28

Table 6. Magnetic field levels inside the pickup truck within 30 feet of the 10- or 15-MHz antenna in A/m

Location	Measurement height	Frequency (MHz)			
		2.5	5	10	15
Driving around the 10-MHz antennas for 2 minutes	Head (window)	0.01	0.009	0.028	0.008
Driving around the 15-MHz antennas for 2 minutes	Head (window)	0.009	0.009	0.009	0.031
ICNIRP OEL (reference levels for occupational exposure)		0.64	0.32	0.16	0.16
ICNIRP action level (reference levels for general public exposure)		0.3	0.15	0.073	0.073

Conclusions

Electric and magnetic field strengths measured in the cab of the pickup truck driving near transmitting antennas were below the OELs and action levels. Electric and magnetic field strengths measured on the roof, in the office, and in the transmission room of the radio station building were below the OELs and action levels. Electric field strengths measured near the 5-, 10-, and 15-MHz antennas exceeded the OELs, but employees spent little time in the antenna field. During activities involving primary or backup antennas that were powered off, or when servicing the weather station, employees could be overexposed to magnetic fields induced from nearby transmitting antennas.

Recommendations

On the basis of our findings, we recommend the actions listed below to create a safer workplace. We encourage the research institution to use a labor-management health and safety committee or working group to discuss the recommendations in this report and develop an action plan. Those involved in the work can best set priorities and assess the feasibility of our recommendations for the specific situation at the research institution.

1. Develop a comprehensive RF safety program. According to our measurements, the radio station meets the criteria of a category three RF safety program, defined as a site with the "potential to exceed the exposure limit in accessible areas, if mitigating controls are not applied" [IEEE 2005a].

2. Assign a programmatic RF safety officer to develop and oversee the overall RF safety plan for all research sites in this institution [IEEE 2005a]. Assign a deputy RF safety officer at this research site.
3. Maintain an inventory of RF sources that have the potential to produce electric and magnetic field strengths near or above OELs or action levels. Conduct initial exposure monitoring when new sources are introduced and additional exposure monitoring when processes are modified.
4. Follow IEEE guidelines for signs (IEEE Standard C95.7-2005, Section 4.3.2.1) in areas where action levels may be exceeded and caution signs in areas where OELs may be exceeded.
5. Power off the standby 5-MHz antenna when employees maintain the weather station to lower their exposures to electric and magnetic fields.
6. Confirm the effectiveness of reducing the power to a transmitting antenna as a control measure to reduce induced field strengths when employees are working on a nearby powered off antenna by doing field strengths measurements and body-current exposure monitoring.
7. Confirm the effectiveness of using a bucket or scissor lift as a control measure to reduce induced field strengths when employees service the weather station by doing field strength measurements and body-current exposure monitoring.
8. Provide annual RF safety awareness training. Educate employees on the potential hazards associated with RF exposures, the purpose of signage, and other safety procedures such as lockout/tagout.
9. Modify the incident reporting system to include possible RF overexposure incidents, such as medical device interference, reddening of skin, elevated body temperatures, other evidence of burns, and electrical shocks.
10. Audit the RF safety program annually. This audit should include a review of RF overexposure incidents and RF monitoring data, and inspection of controls. Review feedback and recommendations from employees submitted to the RF safety officer and/or deputy.

Appendix A: Occupational Exposure Limits and Health Effects

NIOSH investigators refer to mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents when evaluating workplace hazards. OELs have been developed by federal agencies and safety and health organizations to prevent adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure that most employees may be exposed to for up to 10 hours per day, 40 hours per week, for a working lifetime, without experiencing adverse health effects. However, not all employees will be protected if their exposures are maintained below these levels. Some may have adverse health effects because of individual susceptibility, a pre-existing medical condition, or hypersensitivity (allergy). In addition, some hazardous substances act in combination with other exposures, with the general environment, or with medications or personal habits of the employee to produce adverse health effects. Most OELs address airborne exposures, but some substances can be absorbed directly through the skin and mucous membranes.

Most OELs are expressed as a time-weighted average exposure. A time-weighted average exposure refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended short term exposure limit or ceiling values. Unless otherwise noted, the short term exposure limit is a 15-minute time-weighted average exposure. It should not be exceeded at any time during a workday. The ceiling limit should not be exceeded at any time.

In the United States, OELs have been established by federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits; others are recommendations.

- The U.S. Department of Labor Occupational Safety and Health Administration permissible exposure limits (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits. These limits are enforceable in workplaces covered under the Occupational Safety and Health Act of 1970.
- NIOSH recommended exposure limits are recommendations based on a critical review of the scientific and technical information and the adequacy of methods to identify and control the hazard. NIOSH recommended exposure limits are published in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 2010]. NIOSH also recommends risk management practices (e.g., engineering controls, safe work practices, employee education/training, personal protective equipment, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects.
- Other OELs commonly used and cited in the United States include threshold limit values (TLVs), which are recommended by ACGIH, a professional organization, and workplace environmental exposure levels (WEELs), which are recommended by the American Industrial Hygiene Association, another professional organization. The TLVs

and WEELs are developed by committee members of these associations from a review of the published, peer-reviewed literature. These OELs are not consensus standards. TLVs are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2013]. WEELs have been established for some chemicals "when no other legal or authoritative limits exist" [AIHA 2013].

Outside the United States, OELs have been established by various agencies and organizations and include legal and recommended limits. The Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (Institute for Occupational Safety and Health of the German Social Accident Insurance) maintains a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at http://www.dguv.de/ifa/Gefahrstoffdatenbanken/GESTIS-Internationale-Grenzwerte-für-chemische-Substanzen-limit-values-for-chemical-agents/index-2.jsp, contains international limits for more than 1,500 hazardous substances and is updated periodically.

The Occupational Safety and Health Administration requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970 (Public Law 91–596, sec. 5(a)(1))]. This is true in the absence of a specific OEL. It also is important to keep in mind that OELs may not reflect current health-based information.

When multiple OELs exist for a substance or agent, NIOSH investigators generally encourage employers to use the lowest OEL when making risk assessment and risk management decisions. NIOSH investigators also encourage use of the hierarchy of controls approach to eliminate or minimize workplace hazards. This includes, in order of preference, the use of (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation), (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection). Control banding, a qualitative risk assessment and risk management tool, is a complementary approach to protecting employee health. Control banding focuses on how broad categories of risk should be managed. Information on control banding is available at http://www.cdc.gov/niosh/topics/ctrlbanding/. This approach can be applied in situations where OELs have not been established or can be used to supplement existing OELs.

Radiofrequency Health Effects

Electrical currents cause electric and magnetic fields which can be high or low in intensity, and continuous or brief in duration. However, once electrical power is turned off, none of the fields linger in the environment. Electric fields, such as those present around power lines and broadcasting antennas, are strongest at their source. These fields are reduced by walls, buildings, and trees. Like electric fields, magnetic fields are strongest close to their source

and rapidly decrease with increased distance from the source. Unlike electric fields, magnetic fields are not effectively blocked by common materials such as walls or floors of buildings [WHO 2010].

Much of what is known about RF biological effects pertains to acute (short-term) exposure; relatively little is known about the effects of long-term low-level RF exposure. Human and animal studies show that exposure to RF fields above OELs may cause harmful biological effects as a result of heating of internal tissues. The extent of heating depends primarily on the RF frequency, intensity of the RF field, and duration of exposure. However, some researchers have reported that absorption of RF radiation may result in nonthermal effects that occur without a measurable increase in tissue temperature, and at RF field strengths lower than those that cause thermal effects [NIOSH/OSHA 1979; FCC 1999]. As noted in IEEE C95.1-1999, nonthermal mechanisms, such as the electrostimulation of excitable cells (nerve stimulation) become important at frequencies between 3 kilohertz (kHz) and 100 kHz. Research suggests that fields less than 30 kHz could cause significant biological responses by stimulating the nervous or cardiac systems [Bernhardt 1979; Bailey et al. 1997].

Exposure to RF radiation below 0.1 MHz requires special consideration and treatment to prevent electrical shock; induction of RF currents in conductive objects may induce currents through the body of an individual who contacts them. The amount of current that flows through a body depends on how well the individual is electrically grounded and the impedance between the source and the individual.

Radiofrequency Occupational Exposure Limits

Most RF exposure levels are intended to protect against acute health effects associated with electrostimulation (shocks or pain associated with induced body currents) and tissue and whole body heating (RF burns) [IEEE 2005b]. An extensive review of the scientific literature on possible health effects from RF exposure was published in 2009 by the International Commission on Non-Ionizing Radiation Protection [ICNIRP 2009]. The authors of this study reviewed biophysical, cellular, animal, human laboratory, and epidemiologic studies, and concluded that there was no evidence of any other health effects related to RF exposure [ICNIRP 2009].

The ICNIRP reference levels for time-varying electromagnetic fields (up to 300 Hz) are based on short-term, immediate health effects such as stimulation of peripheral nerves and muscles, shocks and burns caused by touching conductive objects, and elevated tissue temperatures resulting from absorption of energy during exposure to electromagnetic fields [ICNIRP 1998]. The IEEE maximum permissible exposures for RF radiation (3 kHz to 300 gigahertz [GHz]) are intended to minimize painful electrostimulation in the frequency range of 3 kHz to 5 MHz and to protect against adverse heating in the frequency range of 100 kHz to 300 GHz. In the transition region of 100 kHz to 5 MHz, the maximum permissible exposures are intended to protect against both electrostimulation and thermal effects [IEEE 2005b].

The Federal Communications Commission (FCC) maximum permissible exposures are intended to prevent similar health effects [FCC 1999]. The ACGIH TLVs for RF and microwave radiation are based on its thermal effects [ACGIH 2013]. Two areas of the body, the eyes and the testes, are known to be particularly vulnerable to heating by RF energy because of the relative lack of available blood flow to dissipate the excessive heat load. Intense RF exposures to the eyes of animals have been shown to cause cataracts. Intense RF exposures to the testes of animals have been shown to cause temporary sterility [FCC 1999].

During this evaluation, the atomic time radio station transmitted high frequency (2.5–15 MHz) signals. Tables A1 and A2 present the OELs and action levels for electric and magnetic field strengths corresponding to these frequencies.

Table A1. RLs, OELs, and action levels (RMS values averaged over 6 minutes) for electric field strengths (V/m) with the most conservative exposure levels bolded and action levels underlined

Frequency (MHz)	ICNIRP		IEEE		ACGIH		FCC	
	RL	Action level	RL	Action level	TLV	Action level	RL	Action level
2.5	**244**	55	737	330	737	147	614	330
5	**122**	40	368	165	368	74	368	165
10	**61**	28	184	82	184	37	184	82
15	**61**	28	123	55	123	25	123	55

RL = Reference Level

Table A2. RLs, OELs, and action levels (RMS values averaged over 6 minutes) for magnetic field strengths (A/m) with the most conservative exposure levels bolded and action levels underlined

Frequency (MHz)	ICNIRP		IEEE		ACGIH		FCC	
	RL	Action level	RL	Action level	TLV	Action level	RL	Action level
2.5	**0.64**	0.3	6.5	6.5	6.5	1.30	1.63	0.88
5	**0.32**	0.15	3.3	3.3	3.3	0.65	0.98	0.44
10	**0.16**	0.073	1.6	1.6	1.7	0.33	0.49	0.22
15	**0.16**	0.073	1.1	1.1	1.1	0.22	0.33	0.15

The OELs include ICNIRP reference levels for occupational exposures [ICNIRP 1998], IEEE maximum permissible exposures for people in controlled environments [IEEE 2005b], ACGIH TLVs [ACGIH 2013], and FCC limits for occupational/controlled exposure [FCC 1999]. According to IEEE Standard C95.7, action levels are any of the following criteria: the lower tier limits of IEEE Standard C95.1, the general public guidelines of ICNIRP, 1/5 of the ACGIH TLVs, and the general public/uncontrolled exposure limits of the FCC [IEEE 2005a].

For this evaluation, the most conservative OELs and action levels were used for making decisions regarding the implementation of RF field safety program elements. ICNIRP levels are the most conservative for all of the frequencies we evaluated with the exception of electric field strength at 15-MHz. In this case, the ACGIH action level is most conservative (Appendix A, Table A1).

Appendix B: Tables

Table B1. 15-MHz outdoor electric field measurements*

Location	Measurement height	GPS coordinates	Results (V/m)
30 feet, 130° SE of 15-MHz antenna	Groin	21 59.429 – 159 45.835	**129**
30 feet, 130° SE of 15-MHz antenna (6-minute averaging time)	Groin	21 59.429 – 159 45.835	**93.2**
180° S of 15-MHz standby antennas (centerline)	Groin	21 59.206 – 159 45.818	**92.7**
30 feet, 130° SE of 15-MHz antenna	Groin	21 59.429 – 159 45.835	**92.3**
340° N of 15-MHz standby antennas (centerline)	Groin	21 59.206 – 159 45.818	**89.8**
30 feet, 130° SE of 15-MHz antenna	Head	21 59.429 – 159 45.835	**85**
30 feet, 130° SE of 15-MHz antenna	Chest	21 59.429 – 159 45.835	**84.5**
At fence, W/SW of the standby 15-MHz antenna	Groin	21 59.208 – 159 45.823	50.9
Standby 15-MHz antenna nearest building (off and grounded at the transmitter)	10 feet high	Not collected	37
At the base of the standby 15-MHz antenna nearest beach (off and grounded at the transmitter)	1 foot	Not collected	10.8
Driving around the 15-MHz antennas for 2 minutes (averaging time)	Head (window)	Not collected	3.8
ICNIRP OEL (reference levels for occupational exposure)			61
ICNIRP action level (reference levels for general public exposure)			28†

*30-second averaging time unless otherwise noted

†ACGIH action level = 25 V/m (more conservative than ICNIRP at 15-MHz)

Measurements exceeding occupational exposure limits are bolded.

Measurements exceeding action levels are underlined.

Table B2. 15-MHz outdoor magnetic field measurements*

Location	Measurement height	GPS coordinates	Results (A/m)
340° N of 15-MHz standby antennas (centerline)	Groin	21 59.214 – 159 45.818	**0.29**
180° S of 15-MHz standby antennas (centerline)	Groin	21 59.206 – 159 45.818	**0.21**
Standby 15-MHz antenna nearest building (off and grounded at the transmitter)	10 feet	Not collected	**0.17**
At fence, W/SW of the standby 15-MHz antenna	Groin	21 59.208 – 159 45.823	0.13
30 feet, 130° SE of 15-MHz antenna	Head	21 59.429 – 159 45.835	0.12
30 feet, 130° SE of 15-MHz antenna	Chest	21 59.429 – 159 45.835	0.1
30 feet, 130° SE of 15-MHz antenna	Groin	21 59.429 – 159 45.835	0.093
30 feet, 130° SE of 15-MHz antenna (6-minute average)	Groin	21 59.429 – 159 45.835	0.093
At the base of standby 15-MHz antenna nearest beach (off and grounded at the transmitter)	1 foot	Not collected	0.049
Driving around the 15-MHz antennas for 2 minutes (averaging time)	Head (window)	Not collected	0.031
ICNIRP OEL (reference levels for occupational exposure)			0.16
ICNIRP action level (reference levels for general public exposure)			0.073

*30-second averaging time unless otherwise noted

Measurements exceeding occupational exposure limits are bolded.

Measurements exceeding action levels are underlined.

Table B3. 10-MHz outdoor electric field measurements*

Location	Measurement height	GPS coordinates	Results (V/m)
At fence, 125° E/SE of standby 10-MHz antenna	Groin	21 59.307 – 159 45.804	**79.2**
30 feet, 200° S/SW of 10-MHz antenna	Groin	21 59.297 – 159 45.859	**74.4**
30 feet from orange fence, 200° S/SE of 10-MHz antenna	Chest	Not Collected	**69.2**
30 feet, 200° S/SW of 10-MHz antenna	Groin	21 59.297 – 159 45.859	**67.4**
30 feet, 200° S/SW of 10-MHz antenna	Chest	21 59.297 – 159 45.859	**64.6**
30 feet from orange fence, 200° S/SE of 10-MHz antenna	Groin	Not collected	**62.9**
30 feet, 200° S/SW of 10-MHz antenna (6-minute averaging time)	Groin	21 59.297 – 159 45.859	**62.3**
30 feet, 200° S/SW of 10-MHz antenna	Head	21 59.297 – 159 45.859	**61.7**
30 feet from orange fence, 200° S/SE of 10-MHz antenna	Head	Not collected	60.95
15 feet from fence, 125° E/SE of standby 10-MHz antenna	Groin	Not collected	42.1
At the grounding wire for the standby 10-MHz antenna	1 foot	Not collected	22.4
At the base of the standby 10-MHz antenna (off and grounded at tuning box)	1 foot	Not collected	16.2
At the grounded tuning box for the standby 10-MHz antenna	1 foot	Not collected	11
Driving around the 10-MHz antennas for 2 minutes (averaging time)	Head (window)	Not collected	4.81
ICNIRP OEL (reference levels for occupational exposure)			61
ICNIRP action level (reference levels for general public exposure)			28

*30-second averaging time unless otherwise noted

Measurements exceeding occupational exposure limits are bolded.

Measurements exceeding action levels are underlined.

Table B4. 10-MHz outdoor magnetic field measurements*

Location	Measurement height	GPS coordinates	Results (A/m)
At the base of the standby 10-MHz antenna (off and grounded at tuning box)	1 foot	Not collected	**0.198**
30 feet, 200° S/SW of 10-MHz antenna	Groin	21 59.297 – 159 45.859	**0.19**
30 feet from orange fence, 200° S/SE of 10-MHz antenna	Groin	Not collected	**0.16**
30 feet from orange fence, 200° S/SE of 10-MHz antenna	Chest	Not collected	**0.16**
30 feet from orange fence, 200° S/SE of 10-MHz antenna	Head	Not collected	**0.16**
30 feet, 200° S/SW of 10-MHz antenna	Chest	21 59.297 – 159 45.859	0.118
30 feet, 200° S/SW of 10-MHz antenna	Head	21 59.297 – 159 45.859	0.118
At fence, 125° E/SE of standby 10-MHz antenna	Groin	21 59.307 – 159 45.804	0.054
On roof corner, near pole, 120° E/SE of standby 10-MHz antenna (on)	Groin	21 59.279 – 159 45.787	0.05
Driving around the 10-MHz antennas for 2 minutes (averaging time)	Head (window)	Not collected	0.0275
At the grounded tuning box for the standby 10-MHz antenna	1 foot	Not collected	0.02
ICNIRP OEL (reference levels for occupational exposure)			0.16
ICNIRP action level (reference levels for general public exposure)			0.073

*30-second averaging time unless otherwise noted

Measurements exceeding occupational exposure limits are bolded.

Measurements exceeding action levels are underlined.

Table B5. 5-MHz outdoor electric field measurements*

Location	Measurement height	GPS coordinates	Results (V/m)
Directly in the middle of the 5-MHz antennas	Groin	Not collected	**143**
3 feet from fence surrounding 5-MHz antenna	Groin	Not collected	**134**
Next to fence facing the building surrounding the standby 5-MHz antenna	Groin	Not collected	84.3
Near guide wire between 5-MHz antenna (on block)	Groin	Not collected	70.2
15 feet from the 5-MHz antenna	Groin	Not collected	67.7
25 feet, S of fence surrounding 5-MHz antenna (between guide wires)	Groin	21 59.182 – 159 45.756	57.9
5-MHz antenna western guide wire	Groin	Not collected	30.9
Next to the building across from the standby 5-MHz antenna	Groin	Not collected	5.01
ICNIRP OEL (reference levels for occupational exposure)			122
ICNIRP action level (reference levels for general public exposure)			40

*30-second averaging time unless otherwise noted

Measurements exceeding occupational exposure limits are bolded.

Measurements exceeding action levels are underlined.

Table B6. 5-MHz outdoor magnetic field measurements*

Location	Measurement height	GPS coordinates	Results (A/m)
Next to fence facing the building surrounding the standby 5-MHz antenna	Groin	Not collected	**0.389**
15 feet from the 5-MHz antenna	Groin	Not collected	0.245
Near guide wire between 5-MHz antenna (on block)	Groin	Not collected	0.13
25 feet, S of fence surrounding 5-MHz antenna (between guide wires)	Groin	21 59.182 – 159 45.756	0.0887
5-MHz antenna western guide wire	Groin	Not collected	0.0874
3 feet from fence surrounding 5-MHz antenna	Groin	Not collected	0.0794
Directly in the middle of the 5-MHz antennas	Groin	Not collected	0.055
Corner of PV array nearest 5-MHz standby antenna	about 14 feet	21 59.254 – 159 45.769	0.0394
Next to the building across from the standby 5-MHz antenna	Groin	Not collected	0.036
ICNIRP OEL (reference levels for occupational exposure)			0.32
ICNIRP action level (reference levels for general public exposure)			0.15

*30-second averaging time unless otherwise noted

Measurements exceeding occupational exposure limits are bolded.

Measurements exceeding action levels are underlined.

Table B7. 2.5-MHz outdoor electric field measurements*

Location	Measurement height	GPS coordinates	Results (V/m)
At fence, 220° W/SW of 2.5-MHz standby antenna	Groin	21 59.317 – 159 45.774	130
10 feet from the fence surrounding the 2.5-MHz antenna	Groin	Not collected	58.4
25 feet, 175° S of fence surrounding the 2.5-MHz antenna near conduit	Groin	21 59.343 – 159 45.874	46.4
6 feet from sand line surrounding the 2.5-MHz antenna	Groin	Not collected	42.1
15 feet, 232° W/SW of the 2.5-MHz antenna	Groin	21 59.349 – 15 45.880	34.6
ICNIRP OEL (reference levels for occupational exposure)			244
ICNIRP action level (reference levels for general public exposure)			55

*30-second averaging time unless otherwise noted

Measurements exceeding action levels are underlined.

Table B8. 2.5-MHz outdoor magnetic field measurements*

Location	Measurement height	GPS coordinates	Results (A/m)
At fence, 220° W/SW of 2.5-MHz standby antenna	Groin	21 59.317 – 159 45.774	0.61
10 feet from the fence surrounding the 2.5-MHz antenna	Groin	Not collected	0.338
6 feet from sand line surrounding the 2.5-MHz antenna	Groin	Not collected	0.33
25 feet, 175° S of fence surrounding the 2.5-MHz antenna near conduit	Groin	21 59.343 – 159 45.874	0.29
15 feet, 232° W/SW of the 2.5-MHz antenna	Groin	21 59.349 – 15 45.880	0.221
ICNIRP OEL (reference levels for occupational exposure)			0.64
ICNIRP action level (reference levels for general public exposure)			0.3

*30-second averaging time unless otherwise noted

Measurements exceeding action levels are underlined.

Table B9. Miscellaneous outdoor electric field measurements (V/m)*

Location	Measurement height	GPS coordinates	Frequency (MHz) 2.5	5	10	15
Next to the weather station receiving antenna (5- and 10-MHz standby antennas on)	Groin	21 59.263 – 159 45.774	1.26	11.7	2.49	3.14
1/3 of the way up the weather station antenna	about 8 feet	21 59.263 – 159 45.774	4.6	66	10.2	20
1/2 of the way up the weather station antenna	about 16 feet	21 59.263 – 159 45.774	5.98	75.8	9.2	10.4
Corner of PV array nearest 5-MHz standby antenna	about 14 feet	21 59.254 – 159 45.769	4.3	20.1	3.8	2.7
On roof, 350° N/NW (nearest) of the weather station antenna (with standby 5- and 10-MHz antennas on)	Groin	21 59.270 – 159 45.779	5.17	13.6	10.69	3.98
On roof corner, near pole, 120° E/SE of standby 10-MHz antenna (on)	Groin	21 59.279 – 159 45.787	13.58	18.8	16.7	6.62
1/2 way between 2.5- and 10-MHz antennas, 330° from the 10-MHz	Groin	21 59.329 – 159 45.865	14	3.38	15.45	2.12
Between the 10- and 15-MHz antennas, 106 feet (345° N/NE) from the 15-MHz antenna	Chest	21 59.274 – 159 45.884	6.23	4.38	15.03	17.89
Between the 10- and 15-MHz antennas, 106 feet (345° N/NE) from the 15-MHz antenna	Head	21 59.274 – 159 45.884	5.86	4.5	15.3	18.55
Between the 10- and 15-MHz antennas, 106 feet (345° N/NE) from the 15-MHz antenna	Groin	21 59.274 – 159 45.884	6.21	4.2	16.88	17.85
Between the 5- and 15-MHz antennas, 265 feet (140° SE) from the 15-MHz antenna	Groin	21 59.225 – 159 45.804	4.09	19.87	1.45	3.4
80 inches from the NE corner of building outside secretary's office	Head	Not collected	12.1	2.01	0.97	1.07
ICNIRP OEL (reference levels for occupational exposure)			244	122	61	61
ICNIRP action level (reference levels for general public exposure)			55	40	28	28†

*30-second averaging time unless otherwise noted

†ACGIH action level = 25 V/m (more conservative than ICNIRP at 15-MHz)

Measurements exceeding action levels are underlined.

Table B10. Miscellaneous outdoor magnetic field measurements (A/m)*

Location	Measurement height	GPS coordinates	Frequency (MHz)			
			2.5	5	10	15
On roof, 350° N/NW (nearest) of the weather station antenna (with standby 5- and 10-MHz antennas on)	Groin	21 59.270 – 159 45.779	0.011	0.032	0.016	0.017
On roof corner, near pole, 120° E/SE of standby 10-MHz antenna (on)	Groin	21 59.279 – 159 45.787	0.016	0.037	0.050	0.021
Next to the weather station receiving antenna (5- and 10-MHz standby antennas on)	Groin	21 59.263 – 159 45.774	0.015	<u>0.164</u>	0.019	0.018
1/3 of the way up the weather station antenna	about 8 feet	21 59.263 – 159 45.774	0.025	<u>0.274</u>	0.032	0.024
1/2 of the way up the weather station antenna	about 16 feet	21 59.263 – 159 45.774	0.027	**0.349**	0.049	0.039
1/2 way between 2.5- and 10-MHz antennas, 330° from the 10-MHz	Groin	21 59.329 – 159 45.865	0.032	0.01	0.043	0.009
Between the 10- and 15-MHz antennas, 106 feet (345° N/NE) from the 15-MHz antenna	Chest	21 59.274 – 159 45.884	0.014	0.013	0.027	0.038
Between the 10- and 15-MHz antennas, 106 feet (345° N/NE) from the 15-MHz antenna	Head	21 59.274 – 159 45.884	0.014	0.012	0.027	0.04
Between the 10- and 15-MHz antennas, 106 feet (345° N/NE) from the 15-MHz antenna	Groin	21 59.274 – 159 45.884	0.014	0.013	0.026	0.035
Between the 5- and 15-MHz antennas, 265 feet (140° SE) from the 15-MHz antenna	Groin	Not collected	0.011	0.03	0.009	0.01
80 inches from the NE corner of building outside secretary's office	Head	Not collected	0.032	0.015	0.014	0.008
ICNIRP OEL (reference levels for occupational exposure)			0.64	0.32	0.16	0.16
ICNIRP action level (reference levels for general public exposure)			0.3	0.15	0.073	0.073

*30-second averaging time unless otherwise noted

Measurements exceeding occupational exposure limits are bolded.

Measurements exceeding action levels are underlined.

Table B11. Indoor electric field measurements (V/m)*

Location	Frequency (MHz)			
	2.5	5	10	15
Inside transmitter room by primary 2.5-MHz transmitter	0.330	0.420	0.460	0.182
Inside transmitter room by primary 5-MHz transmitter	0.299	0.510	0.190	0.210
Inside transmitter room by primary 10-MHz transmitter	0.230	0.257	0.288	0.297
At dean's desk, by window	0.620	3.900	0.830	0.357
Inside transmitter room backside of primary 10-MHz cabinet (power off to simulate maintenance)	0.290	0.190	0.540	0.390
Inside transmitter room backside of primary 10-MHz transmitter	0.270	0.170	0.266	0.423
Inside transmitter room by primary 15-MHz transmitter	0.260	0.172	0.187	0.622
Middle of secretary's workstation	14.1	1.21	1.49	0.792
Inside transmitter room between primary 10-MHz and 2.5-MHz transmitters	0.829	1.290	2.190	0.885
Inside transmitter room by standby 5-MHz transmitter (not on)	0.490	0.280	0.185	1.870
Inside transmitter room by standby 15-MHz transmitter (not on)	0.430	0.280	0.150	1.890
Inside cabinet	0.345	0.760	4.310	3.090
At desk near window	0.929	5.044	0.529	Not Collected
ICNIRP OEL (reference levels for occupational exposure)	244	122	61	61
ICNIRP action level (reference levels for general public exposure)	55	40	28	28†

*30-second averaging time unless otherwise noted

†ACGIH action level = 25 V/m (more conservative than ICNIRP at 15-MHz)

Table B12. Indoor magnetic field measurements (A/m)*

Location	Frequency (MHz)			
	2.5	5	10	15
Inside transmitter room backside of primary 10-MHz cabinet (power off to simulate maintenance)	0.01	0.003	0.009	0.003
Inside transmitter room backside of primary 10-MHz transmitter	0.012	0.003	0.004	0.003
Inside transmitter room by primary 15-MHz transmitter	0.003	0.003	0.0023	0.006
Middle of secretary's workstation	0.052	0.015	0.01	0.008
Inside transmitter room by standby 15-MHz transmitter (not on)	0.003	0.003	0.002	0.008
Inside transmitter room by standby 5-MHz transmitter (not on)	0.003	0.003	0.002	0.009
Inside cabinet	Not collected	Not collected	0.013	0.0121
At dean's desk, by window	0.0042	0.014	0.004	0.002
At desk near window	0.0070	0.011	0.005	0.002
ICNIRP OEL (reference levels for occupational exposure)	0.64	0.32	0.16	0.16
ICNIRP action level (reference levels for general public exposure)	0.3	0.15	0.073	0.073

*30-second averaging time unless otherwise noted

Table B13. Spatial average and mixture analysis. Electric field strengths 30 feet, 130° SE of the 15-MHz antenna*

Measurement height	Results (V/m)	Frequency (MHz)				
		2.5	5	10	15	Total Ratio
Head	RMS electric field	4.3	6.1	5.9	**85**	—
	Weighted ratio of OEL	0	0	0.01	1.94	2
	Weighted ratio of action level	0.01	0.02	0.04	11.56	11.6
Chest	RMS electric field	4.5	6.99	5.7	**84.5**	—
	Weighted ratio of OEL	0	0	0.01	1.92	1.9
	Weighted ratio of action level	0.01	0.03	0.04	11.42	11.5
Groin	RMS electric field	4.6	6.4	6.2	**92.3**	—
	Weighted ratio of OEL	0	0	0.01	2.29	2.3
	Weighted ratio of action level	0.01	0.03	0.05	13.63	13.7
Spatial Average	RMS electric field	4.5	6.5	5.9	**87.3**	—
	Weighted ratio of OEL	0	0	0.01	2.1	2.1
	Weighted ratio of action level	0.01	0.03	0.04	12.2	12.3
ICNIRP OEL (reference levels for occupational exposure)		244	122	61	61	—
ICNIRP action level (reference levels for general public exposure)		55	40	28	28†	—

*30-second averaging time unless otherwise noted

†ACGIH action level = 25 V/m (more conservative than ICNIRP at 15-MHz)

Measurements exceeding occupational exposure limits are bolded.

Table B14. Spatial average and mixture analysis. Magnetic field strengths 30 feet, 130° SE of the 15-MHz antenna*

Measurement height	Results (A/m)	Frequency (MHz)				
		2.5	5	10	15	Total Ratio
Head	RMS electric field	0.01	0.02	0.02	<u>0.12</u>	—
	Weighted ratio of OEL	0	0	0.02	0.56	0.6
	Weighted ratio of action level	0	0.02	0.08	2.7	2.8
Chest	RMS electric field	0.013	0.02	0.019	<u>0.1</u>	—
	Weighted ratio of OEL	0	0	0.01	0.39	0.4
	Weighted ratio of action level	0	0.02	0.07	1.88	2
Groin	RMS electric field	0.013	0.018	0.013	<u>0.093</u>	—
	Weighted ratio of OEL	0	0	0.01	0.34	0.3
	Weighted ratio of action level	0	0.01	0.03	1.62	1.7
Spatial Average	RMS electric field	0.012	0.019	0.017	<u>0.10</u>	—
	Weighted ratio of OEL	0	0	0.013	0.43	0.44
	Weighted ratio of action level	0	0.017	0.06	2.07	2.14
ICNIRP OEL (reference levels for occupational exposure)		0.64	0.32	0.16	0.16	—
ICNIRP action level (reference levels for general public exposure)		0.3	0.15	0.073	0.073	—

*30-second averaging time unless otherwise noted

Measurements exceeding action levels are underlined.

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Keywords: North American Industry Classification System 541712 (Research and Development in the Physical, Engineering, and Life Sciences [except Biotechnology]), radiofrequency, RF, radio station, non-ionizing radiation, electric field, magnetic field

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Acknowledgments

Desktop Publishers: Mary Winfree
Editor: Ellen Galloway
Health Communicator: Stefanie Brown
Industrial Hygiene Field Assistance: Michael K. Blumer, NIST
Logistics: Donnie Booher

Availability of Report

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Recommended citation for this report:
NIOSH [2013]. Health hazard evaluation report: evaluation of radiofrequency radiation exposures at an atomic time radio station. By Feldmann K, Fent K. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH Report No. 2011-0097-3200.

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