Section 8

Health Effects Associated with Exposure of Industrial Workers to Radiofrequency Waves

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Summary

- Industrial applications of RF include microwave drying, induction and dielectric heating, broadcasting applications (AM, FM, CB, and TV) and radar; however, exposure assessment has been only done on several of these RF-emitting sources and there are even fewer epidemiological studies of health effects associated with specific industrial sources.
- Well-recognized health effects of acute high level industrial exposures to RF are heating of body tissues (thermal effects) and radiofrequency (RF) induced contact shocks. Occupational exposure limits are designed to prevent these effects. Case reports of acute industrial exposure to RF describe the immediate effects of accidental over-exposure (generally without direct measurement of the level of those exposures), and in most cases with no reported long-term follow up.
- For the most part, workers exposed to RF in the dielectric heating industries have reported similar symptoms to that of non-exposed comparison workers; however, sometimes paresthesia (a burning or prickling sensation that is usually felt in the hands, arms, legs, or feet) is reported more often in exposed workers.
- Brain tumours and cancers of the blood such as leukemia and Hodgkin lymphoma are the most extensively studied cancer outcomes in studies of long-term occupational RF exposure. Overall, observational studies have not shown an increased risk for any cancer site although a few studies have shown some indication of an excess in leukemia in military personnel exposed to radar.
- Studies of cardiovascular mortality in RF-exposed workers have been consistently negative.
- Military personnel were the focus of several studies of the effects of occupational exposure to RF on semen parameters. Although there was some indication of adverse sperm effects, the recruitment of subjects in these studies were either poorly described or there were poor participation rates.
- The few studies on the risk of eye cataracts following occupational RF exposures have shown mixed results.
- The quality of exposure assessment and the relatively small numbers of workers studied are major limitations of observational studies of occupational exposure to RF.
- Further research into health effects associated with occupational exposures to RF is needed, both for what can be learned of the risks of occupational exposure and for what it says about high level exposures in general, given that workers may be exposed to RF at a greater intensity and for longer duration than the general public, and because their exposure may be to lower frequencies of RF which can penetrate more deeply into the body.

8.1 Introduction

There are numerous applications of RF fields in industry. Studies of workers in these industries may provide useful insight into the health risks associated with unique types and levels of exposure to RF.

Many of these applications, such as radar and plastic welding, pre-date by decades the widespread use of mobile phones, permitting assessment of exposures of very long duration.

This section describes principal industrial uses of RF waves and evaluates the literature concerning acute and chronic exposures of industrial workers to RF and associated health effects.

8.2 Industrial Applications of RF

8.2.1 Industrial microwave ovens (dryers)

Industrial microwave ovens use the same principle for heating as household microwave ovens and are generally used for drying wet surfaces, such as building components (ceilings, wall surfaces) and flooded surfaces. They operate at higher power than household ovens (which range from 0.5 to 2 kW) at levels from 1 kW to 5 kW and use 2 frequencies: 915 MHz (wavelength 30 cm) and 2.45 GHz (wavelength 12 cm), which is similar to consumer ovens.

8.2.2 Induction heating

Induction heating is a non-contact heating process that heats conductive material by exposing it to alternating electromagnetic fields. A rapidly alternating magnetic field induces eddy currents in a conductive material placed in its vicinity, heating the material by induction. Induction heating is used to bond, harden or soften metals or other conductive materials. Induction heating is commonly used in several applications in the aviation and automotive industries, in pipe fitting, shipbuilding and foundries. Induction heating uses frequencies ranging from 100 to 500 kHz and powers up to 500 kW.

8.2.3 Dielectric heating

Dielectric heating is a technique used for heating nonconductive materials from the inside to high temperatures by means of high-frequency alternating continuous RF fields. It is commonly used for welding plastic parts, sealing plastic bags, drying and bending pieces of wood, drying ceramics, sterilizing foods, pre-vulcanizing rubbers, drying and bonding textiles and other such uses.

The frequencies used in dielectric heating range from 5 MHz to 80 MHz and powers from 5 to 450 kW.

8.2.4 Installation and maintenance of mobile phone base stations

Mobile phone base stations are used in telecommunications to send to and receive RF signals from mobile phones. The frequencies used are usually from 900 MHz to 2.45 GHz while the powers range from 1 W for antennas inside buildings to 40 W for antennas sited at high elevations.

The installation and maintenance of mobile phone base stations is supposed to be conducted with the RF beam turned off, thus with no risk to workers.

8.2.5 Broadcasting applications: AM, FM, CB, and TV

RF waves are largely used for radio and television broadcasting. Radio broadcasting stations emit in different frequency and power ranges, depending on the type of emissions. Amplitude modulation (AM) radio operates at frequencies from 550 to 1600 kHz while frequency modulation (FM) radio uses frequencies from 88 to 108 MHz. Both AM and FM use a range of powers from few hundred Watts to 45 kW depending on the scale of the areas covered. Citizens band (CB) radio operates at 27 MHz and uses a power of 4 W. TV broadcasting stations emit in the 470–854 MHz range at a power close to 1 Megawatt (MW). Radio and TV broadcasting installations are generally considered safe work places. However, when working close to antennas for maintenance or repairs, precautions must be taken to avoid over-exposure.

8.2.6 Radar

Radar systems are used for detecting objects and measuring the distance separating them from the RF antenna (ranging). Radars transmit RF waves by directive antennas aimed towards a target; a portion of the RF energy is reflected back to the radar, thus potentially exposing the operator. Radar emissions can be continuous (cw radar) or pulsed (pulsed radar).

The main uses of radar is in air traffic control, air navigation, ship safety, speed limit enforcement on roads, weather monitoring, and military applications.

Radars use a typical power of 1 Kilowatt (kW) and their frequencies range from 3 MHz to 40 GHz, depending on the type of use.

8.3 Occupational Risks Associated with RF

8.3.1 Methods

A literature search was conducted to identify peer-reviewed articles relating to occupational exposure to RF and its health effects. Two databases, Medline and EBSCO were used. Key terms used were: radio waves, microwaves, electromagnetic radiation, electromagnetic field, occupational exposure, occupational diseases, as well as specific industries: plastic welders, amateur radio operators, broadcast station and radar. There were no date limits, but studies were limited to English only. Three literature reviews of observational studies of RF which included occupational exposures were identified: Breckenkamp et al. (2002), Ahlbom et al. (2004) and Habash et al. (2009).[1-3] These reviews included most of the observational studies identified in the literature search, with the exception of a 2006 case-control study done as part of the Interphone project,[4] a 2009 retrospective cohort study on military radar operators[5] and a small 2007 case-control study on non-Hodgkin lymphoma involving exposure to both ionizing and non-ionizing radiation.[6]

8.3.2 Assessment of occupational exposures to RF

Exposure assessment is consistently reported as the greatest limitation to the interpretation of studies on the effect of both acute and chronic occupational exposure to RF.[7] Acute exposures to RF typically involve accidental exposures with exposure estimates based on reconstruction of the event.

Epidemiological studies of chronic exposure most commonly use job titles to assign workers to exposure categories. The precision of exposure categories varies widely and may be based on measurements assigned to groups of workers or the expert opinion of industrial hygienists used to estimate exposure for a given worksite or job title or on self-reported exposure to workspace or source equipment.

In reviewing studies on the health effects of occupational RF exposure, important considerations are the factors that affect exposure to RF and the fact that RF exposure does not usually occur in isolation from other exposures to EMF, such as Extremely Low Frequency radiation or to industrial contaminants such as metals or ionizing radiation. As such, it is difficult to attribute health outcomes to RF exposure alone. The majority of the studies on health effects of occupational exposure to RF do not contain information on exposure measurements nor do they contain enough information about the factors that have an effect on personal exposures, as described in Section 5:

- Output power of the RF source, number of RF sources
- Whether an antenna is directional or omnidirectional
- Frequency of RF waves
- Duty cycle of the RF generator
- Continuous vs. pulsed waves
- Distance and location of the worker from the RF source (e.g., in the radiated lobe of source)
- Presence of barriers, reflective surfaces (i.e., that either decrease or increase exposure)
- Duration of exposure, frequency of exposure
- Whether the exposure is to the whole body or is localized.

Occupational exposures to RF are much different from public exposures in that occupational populations are potentially exposed to much higher RF power densities. Other than broadcast or mobile phone base station operators, most other workers (e.g., police using radar guns, RF sealers/plastic welders, and radio/telegraph workers) are exposed to RF in frequencies outside those normally found for public exposures and therefore any exposure information obtained about these populations are not directly applicable to public health. At lower wave frequencies, experienced by RF plastic welders and telegraph workers, RF penetrates deeper into tissue and below 110 MHz, contact currents may develop, whereas in the general population, contact currents are rarely a concern.

Radar emissions include the frequency range of interest to public health, although source output power levels and therefore occupational exposures are documented as being much higher. Richter et al., 2002 reviews five case reports of military personnel where output power levels ranged from 100 to 300 W and radar frequencies included MHz to GHz ranges.[8] Measurements of radar main beams by Puranen and Jokela (1996)[9] found radar peak output power levels ranging from 125 kW to 3000 kW for stationary radar antennas.

There is a dearth of studies that measure RF exposure to workers. Seventy percent of the studies reviewed are older than 10 years (prior to 2002). Since that time, the technology of exposure assessment has improved and the measurements made in the past may not be as accurate or reliable as measurements made presently. The most promising occupational populations to study for relevant health effects to the public are those who are exposed to frequencies and intensities that are similar to those affecting the public, i.e., broadcast or base station workers. Unfortunately, most of the studies done of these workers were case reports with exposure ascertainment conducted after accidental exposures, with attempts at reconstructing the accident situation rather than measuring more typical exposures. The exception is the exposure assessment study by Alanko and Hietanen (2007) which describes common exposures to broadcast tower workers.[10] Measured exposures were between 0.1 W/m^2 (0.01 mW/cm^2) and 2.3 W/m^2 (0.23 mW/cm^2) for GSM and radio antenna workers (which are well below ICNIRP reference levels).

Accidental exposure to RF was described in two case reports.[11,12] Schilling described three TV antenna installers who were accidentally exposed to RF of 785 MHz frequency for up to five minutes.[11] The survey meter reading reached the full scale of 20 mW/cm^2 at 10 cm from the antenna, but the exposure was most likely higher. In another case study cited by Hocking and Westerman (2001),[12] a rigger was exposed to a CDMA mobile phone station antenna that should have been turned off. His exposure was estimated by reproducing the conditions of the exposure at a later date in the laboratory. The RF level from the antenna at a power of 4 W and frequency of 878.49 MHz was estimated to be only about 0.015–0.06 mW/cm^2 for an exposure of over 1–2 hours.

In summary, exposure ascertainment for occupational sources of RF is rather crude, and important determinants, such as output power and number of RF sources, pulsing of the wave, distance of the worker from the RF sources and duration and frequency of exposure, are often not described. When measured, power output levels (W) can vary widely, as can power densities (W/cm^2).

Table 1 provides exposure assessment information which derives mainly from epidemiological studies concerning effects of workers' chronic exposure to RF. Only studies presenting quantitative exposure measurements were included.

Most of the studies reviewed used area measurements and distance from the source to determine a range of typical chronic exposures. A variety of measurements were done for EMF, including power (W/m^2), magnetic B fields (μT), current densities (mA/m^2) and electric fields (V/m). Military personnel exposed to radar and plastic sealing/welding workers tended to incur higher exposure than allowable levels. The few studies measuring exposure to RF for broadcast/antenna workers were consistently below recommended limits for occupational exposure.

Appendix A describes the current Canadian occupational safety regulations and standards for occupational exposure to RF, including recommendations for precautionary measures for workers exposed to RF.

Table 1. RF exposure measurements of various industrial occupations

Study	Job/Location (Type of study)	Description of Job/Area	RF Frequency	Methods	Exposure	Comments
Alanko and Hietanen (2007)[10]	Antenna/ broadcast workers; Finland Exposure assessment study only	Typical working tasks around or inside antenna masts include antenna maintenance, painting, tightening the bolts, beacon replacement, and tower rigging and replacement. Mast 1: 82 m high where workers climbed inside tower; Mast 2: 62 m high where workers had to climb outside of the tower	Mast 1: GSM 900 and GSM 1800 cellular phone networks, and also local radio and amateur radio antennas Mast 2: Only GSM 1800 antennas	Measurements made 2.5 and 3.0 m intervals in a vertical direction, depending on tower type	Mast 1: highest densities at heights of the base stations. For GSM 900 at 63 m and GSM 1800 at 70m, < 0.1 and 0.2 W/m^2, respectively. Increase in power density near the top was due to amateur radio antennas on top of tower (highest instantaneous power density was 0.4 W/m^2 in the climbing space). Mast 2: Two antennas at 28 and 30 m, maximum 0.9 W/m^2. Maximum instantaneous was 2.3 W/m^2, recorded during maintenance tasks of the tower. Below ICNIRP reference levels of 22.5 W/m^2 at 900 MHz and 45 W/m^2 at 1800 MHz.	Exposures were low when ladders are inside the tower, but are higher when the ladders are located outside. According to siting instructions, the antennas should not be directed to pass through the climbing space.
Cooper et al. (2004)[7]	High power –TV and radio broadcast; UK Exposure assessment study only N=27	FM Radio – ERP was 250 kW per channel UHF television – 500 kW per channel at top of 300 m mast	FM Radio UHF television	Personal monitor (incorporated a shaped response to give electric and magnetic field strengths as a percentage of ICNIRP levels) worn by engineer close to high-power VHF antennas	Median – 23.3; Mean – 24.6 (95% CI 19.6–29.6) percent of ICNIRP levels.	Field strengths rarely constant for more than one minute, indicating either power output of transmitters were not constant or position of the monitor was constantly changing.
Cooper et al. (2004)[7]	Medium power broadcast and telecommuni-cations; UK N=15	VHF/UHF 100–200 W with antennas mounted on top of 45 m tower		Personal monitor (incorporated a shaped response to give electric and magnetic field strengths as a percentage of ICNIRP levels)	Percent of ICNIRP levels Median – 10.6; Mean – 10.4 (95% CI 7.8–13.0)	Use of a portable receiver/ transmitter was captured by the personal monitor.

Study	Job/Location (Type of study)	Description of Job/Area	RF Frequency	Methods	Exposure	Comments
Cooper et al. (2004)[7]	Low-power broadcast and telecommunications; UK Mobile phone base stations and other lower-power transmitters (unspecified)	Mobile phone stations	Unspecified frequency	Personal monitor (incorporated a shaped response to give electric and magnetic field strengths as a percentage of ICNIRP levels)	Percent of ICNIRP levels: Median – 9.4; Mean – 8.6 (95% CI 5.5–11.8)	Field strengths generally did not exceed detection threshold, and any that did were brief and of low intensity.
Jokela and Puranen (1999)[13]	Broadcast antennas – UHF-TV and FM antennas	Working near or climbing through transmitting antennas.	TV and FM (50–800 MHz) average power from 10 to 50 kW	Electric field measured inside a section of mast surrounded by a typical dipole-panel type FM antenna	Maximal power density up to 50 W/m^2. Field distribution is highly non-uniform, but average over whole body is above the 10 W/m^2 limit. The 10 W/m^2 level can be exceeded at 50 m and the 100 W/m^2 can be exceeded at 10 m for UHF-TV and FM antennas when a new mast is being built near an old one that is transmitting.	Occupational limits commonly exceeded. Usually for UHF masts, only accidental exposures are possible since entering the radome of the mast is strictly prohibited.
Grajewski et al. (2000)[14]	RF heater/sealer operators; USA Cross-sectional study 27 RF- exposed men and 14 unexposed men	RF sealers and dielectric heaters are used to heat, dry, emboss, melt, seal, or cure materials that are poor. Electrical conductors (dielectric)	12–57 MHz (93% of machines between 20.3 and 32.0 MHz)	Broadband field probes, E and H field strength at eye, chest and groin level, induced current from E- field and frequency. Induced current.	Geometric mean E field ranges (exposed): (1.2 to 9.0) x 10^3 V^2 /m^2 (35 V/m to 95 V/m); B field: (1.9 to 6.4) x 10^{-2} A^2/m^2 (0.14 to 0.25 A/m) Vs. ND for controls. Average induced current 0.7 to 1.3 x 10^2 A vs. ND for controls.	.

Study	Job/Location (Type of study)	Description of Job/Area	RF Frequency	Methods	Exposure	Comments
Bini et al. (1986)[15]	Plastic sealers; Italy Cross-sectional study – operators in room with 67 sealers	Sealers make thermal seams in plastic-sheet articles like inflatable boats.	27.12 MHz and 13.56 MHz Duty cycles of 10% to 70%, entire cycle duration is 1 to 6 minutes in 83% of units.	Measurements made in a room lined with steel sheets to prevent electromagnetic interference from other RF sources. Field strength measured at height of head, abdomen, and hands of operator.	RF-on times are short (a few seconds). At hands, 70% of sealers were above 300 V/m and some up to 4000 V/m. At abdomen, 50% of units were above 300 V/m and at head 70% were above 300 V/m with maximums of 1000 V/m. Exceeded Italian guidelines for electric fields but confined to immediate vicinity of units.	
Wilen et al. (2004)[16]	RF plastic sealers; Sweden Cross-sectional study 46 RF sealers operated by 35 RF operators were measured.	RF is used to produce to heat to seal plastic for things like plastic clothing, tents, and covers. Usually exposure times are for 1-10 secs.	27 MHz	Electric and magnetic field strengths were measured in 7 positions: head, trunk, waist, knees, feet and both hands. Contact currents measured.	Mean electric field and magnetic field averaged over entire body (SD): 88 (102) V/m and 0.19 (0.19) A/m, respectively. Maximum was 2 kV/m and 1.5 A/m at hands. Induced current 101 (147) mA as sum of both feet. Mean value in wrists was 102 (1146) mA.	16 of 46 workplaces exceeded Swedish standard; 11 exceeded ICNIRP levels.
Kolmodin-Hedman et al. (1988)[17]	Plastic welders; Sweden Retrospective cohort study – 113 exposed, 23 control workers	Machines include tarpaulin, ready-made, and automatic.	25-30 MHz	E and B fields measured in frequency range 25 to 30 MHz at least 0.5 m from worker. Measured at area of right and left hands, abdomen, inguinal region, right and left knees, right and left feet (5 times at each location).	50% of welding machines exceeded present Swedish ceiling level of 250 W/m^2. Highest leakage in the ready-made clothing industry.	
Lagorio et al. (1997)[18]	Plastic-ware workers; Italy Retrospective cohort study 302 women and 4 men	Sealing of lifeboats, dinghies, and a few other polyvinyl chloride products.	No frequencies mentioned.	Quantitative RF exposure assessment was considered unattainable.	Findings from mid-1980s survey before metal-shielding or earthing of sealers were adopted showed that levels often exceed10 W/m^2.	

Study	Job/Location (Type of study)	Description of Job/Area	RF Frequency	Methods	Exposure	Comments
Jokela and Puranen (1999)[13]	Plastic sealers Review of exposure assessments		27 MHz (HF sealers for PVC) 13 MHz (glue dryers)	Description from other surveys.	Peak electric field of 2650 W/m² (265 mw/cm²); 600 mA induced current from feet; high local SAR about 20 W/kg per 100 mA (through one foot), maximal SAR peaks may be up to 100 W/kg. Whole body SAR varies from 0.12 to 2 W/kg with 1000 V/m maximal E field.	Exposure assessment is difficult since the operator is in the near field.
Lotz et al. (1995)[19]	Police officers/traffic radar devices; US Exposure assessment study, feasibility study	Use of 10 fixed and hand-held traffic radar devices	24.15 GHz and 10.525 GHz emitting less than 100 mW	Used power density meters, with frequency specific power sensors and standard gain horn antennas, frequency counters, survey meters, and voltmeters. At aperture and 5 and 30 cm in front of antenna, around and behind unit and in the position of operator (head and groin level in absence of operator and at eyes, waist and knees in presence of operator).	Ranged from less than minimum detectable level (MDL) < 0. 020 to 2.60 mW/m² (at waist) when radar gun was resting on passenger seat. Maximum measured at aperture (3.0 mW/m²).	Only in main path were levels above minimum detectable level.
Jokela and Puranen (1999)[13]	Radar	Mechanics testing and maintaining radar systems, soldiers using tactical radars, and occasionally other people working in locations where high power radars are used. High power in a narrow beam and scanning.	3 GHz 9 GHz Power: 125 kW to 3000 kW		In the stationary beam, power density commonly exceeds 100 W/m² and may be up to 1000 W/m2 in front of the antenna. Occupational limit of 50 W/m² may be exceeded at distances of several hundred metres from antenna. Most exposures happen outside the main beam. For high power air surveillance, average power density seldom is above 1 W/m². In tactical radars, where antenna is close to operators, the exposure may exceed 10 W/m2 but not 100 W/m².	

Study	Job/Location (Type of study)	Description of Job/Area	RF Frequency	Methods	Exposure	Comments
Szmigielski (1996)[20]	Military personnel; Poland Retrospective cohort study Mean number= 127,900	All jobs in military 1971-85	150-3500 MHz pulse-modulated	Exposure data taken from health hygienic services of military. Exposure rate hard to establish.	80-85% did not exceed 2 W/m² (0.2 mW/cm²) and others were 2-6 W/m², Exposures exceeding 6 W/m² were registered incidentally.	Daily, monthly exposure was difficult to assess. Not sure how exposure measurements were originally conducted.
Tynes et al. (1996)[21]	Seagoing female radio and telegraph operators - 2619 women; Norway Nested case control study	1961-1991. Exposure to RF in radio rooms ascribed to leakage from unshielded feed lines between antenna and transmitters. Radio officers usually 1-2 meters from transmitters and feed lines.	405 KHz to 25 MHz Also ELF 50 Hz	Operated transmitters at maximum power. Unmodulated transmitted power for telegraphy between 410 and 535 kHz was 1.5 kW. Unmodulated and amplitude modulated telephony were 400 W between 1.6 and 3.6 MHz and 1.5 kW in range 3.6-25 MHz. A distance of 0.5 m was maintained between a field probe and any person was maintained.	At operator desk, below the limit of detection (~20 V/m) at all frequencies, 0.05 A/m for > 3 MHz and 0.15 A/m below 3 MHz. At 0.5 m from tuner (representing worst-case scenario) and 1.5-2m above floor level, E field was 70-200 V/m and H field was 0.1-0.5 A/m, increasing with frequency. Close to unshielded antenna field lines, extreme values of 1400 V/m and 2.5 A/m.	
Skotte (1984)[22]	Danish merchant ships Exposure Assessment study only of telegraphy and telephony equipment	85 measurements of electrical (E) and magnetic (H) field strengths close to 12 radio transmitters	Range of 400 kHz to 25 MHz	Transmitted power from 50 to 200 W Loop antenna (for H-field values < 10 MHz) and HL instrument with probe parallel to the H-field	Ratio of E-field or H-Field squared divided by ANSI standards: Highest values measured at 0.25 m from antenna field line. Range: Ratio of E-field 0.001 to 31 Geometric mean: 0.0089 to 2.3 Range: Ratio of H-field 0.001 to 12 Geometric mean 0.011 to 0.68	Exposure to RF was dependent on the distance between the feed line and the operator and should be < 0.5 for exposure to be below standards.

Converted using: http://www.compeng.com.au/emc_conversion_tables_field_strength_calculator.aspx

8.3.3 Effects of acute occupational exposures to RF

There are two well recognized health effects of acute high level exposures to RF: heating of body tissues (thermal effects) and RF-induced and contact shocks. Exposure to RF at lower frequencies can induce a current in the human body causing depolarization of nerve cells and a shock sensation. Additionally, contact with a conductive object polarized by RF can cause a contact shock or burn. Health Canada's Safety Code 6, which covers human exposure to RF in the range from 3 kHz to 300 GHz, limits exposure to prevent these effects.[23] Animal studies demonstrate alterations in core body temperature of about 1˚C at a whole-body average specific absorption rate (SAR) of 4 W/kg. For controlled environments, a safety factor of 10 is applied, resulting in a whole-body average SAR of 0.4 W/kg (in comparison to levels of 0.08 W/kg for the general public). Limits to prevent induced and contact currents vary depending on the frequency of RF and were selected to avoid shocks and burns, though the induced current may be perceptible at levels below these limits.[23] The health effects of exposure above these limits vary, depending on several factors such as variation in field strength, reflection within the body and individual organs' susceptibility to heat. Distance, shielding and insulation are effective methods to prevent hazards related to heating and contact shocks and burns.

Population health studies of mobile phone use include provocation experiments which allow careful determination of exposure, with sham exposures as a control.[24] Analogous controlled experiments have not been conducted using industrial sources of RF. Knowledge of the acute effects of occupational exposure to RF is mainly derived from case series reports. These reports fall into two broad categories: accidental exposures to RF above recommended limits and studies of the worksite of workers with symptoms attributed to RF exposure.

Hocking et al. (1988)[25] described an Australian overexposure accident involving nine radio linemen. In February 1986, the team was dismantling a television bearer. A waveguide, operating at 4.139 GHz, attached to the bearer was inadvertently activated for 90 minutes. Two members of the team within 2 meters of the waveguide were estimated to have been exposed to 4.6 mW/cm^2 for those 90 minutes; the SAR was estimated to be 3.8 W/kg. This was above the Australian exposure standard, and the SAR approached the level at which thermal effects occur. The other seven members were further away and were estimated to have been exposed to RF of less than 0.15 mW/cm^2. The two highly exposed engineers experienced only a warm sensation during the exposure and no effects were found at a medical exam eight days later. The entire team underwent ophthalmological follow up over a nine-month period and no abnormalities were detected. No further follow-up was undertaken.

Reeves (2000) [26] published a review of 34 American Air Force personnel overexposed to RF between 1973 and 1985 and referred to the US Air Force School of Aerospace Medicine for assessment. Exposures involved a variety of communication and radar equipment and usually resulted from unintentionally leaving equipment active or inappropriately connecting a dummy load to absorb the RF. The frequencies used by the source equipment were not documented or classified for 14 of the cases. The author does not report all the remaining frequencies, but notes that in three cases, equipment used frequencies at 9, 20 and 235 MHz. Estimated power densities varied from below 25 mW/cm^2 to greater than 1500 mW/cm^2; estimates of SAR were not reported. Fourteen workers became aware of the overexposure because of sensation of warmth; several did not become aware of the situation until noting a switch had been left on, or equipment had not been properly connected. Extensive clinical and laboratory assessments failed to demonstrate changes in blood counts, liver and thyroid function. The majority of cases—28—were assessed once; eight others were seen for at least one additional visit. Thirty of the exposed workers underwent psychological assessment due to concerns about mood changes or short-term memory impairment. All abnormalities detected were attributed to pre-existing conditions such as learning disabilities or personality traits; however, at question is the validity of this finding given that there were no baseline data to compare with the assessment results.

In contrast, Schilling (1997)[11] describes the long–term effects of accidental over-exposure in the case of three antenna engineers working on a 785 MHz RF television antennas. Their skip (lift) was wound up instead of down, which exposed them for a few minutes to the near-field of the antenna; their badges registered the full scale of 20 mW/cm^2 and the exposure was likely much higher. After initial erythema, the workers developed symptoms including severe headache, numbness, paresthesia, and malaise, and the headaches persisted during the three to four years of follow up.

In summary, whether or not long-term effects result from acute occupational exposures to RF is difficult to assess without further information on the characteristics and levels of actual exposures at the time of the incident as well as the thoroughness of follow up. Because a mechanism for effects other than thermal effects is unclear and given inconsistent symptom reports, exposure limits have been based only on preventing thermal effects and RF shocks as adopted by Canadian and international organizations.[2,23]

8.3.4 Observational studies of industrial workers chronically exposed to RF

Observational studies of health effects associated with chronic occupational RF exposure include several outcomes:

1. Symptoms
2. Cancer, with most research focusing on brain and hematopoietic cancers
3. Adverse reproductive outcomes, primarily male semen parameters
4. Cardiovascular disease mortality
5. Cataracts

Symptoms: A 2004 Swedish cross-sectional study of 35 RF plastic sealer operators and 37 controls, included exposure assessment of the electric and magnetic field strength "leakage," as well as induced and contact currents.[16] Out of 46 of the plastic sealer units, 11 exceeded ICNIRP reference levels. Examination of the operators showed indications of diminished two-point discrimination ability (2-PD), but the prevalence of any symptom did not differ from controls. For another study of plastic sealer operators,[15] comparison of the health status of 30 exposed operators and 22 unexposed controls showed the prevalence of eye irritation and upper limb paresthesia were significantly higher in the exposed group. Of the 62 female Swedish plastic welders, 53% reported numbness (paresthesia) in the hands in comparison to 22% of the 23 sewing machining operators and assembly worker controls.[17] Diminished 2-PD was significantly greater, affecting 39% of all 113 men and women operators (versus one of the 23 controls). With further measurement of a subset of workers, reporting numbness or demonstrating diminished 2-PD, 12 of 38 had slower conductive velocity. Exposure assessment of the plastic welding machines found more than 50% exceeded the ceiling values for power density of 250 W/m^2.

Overall, there is some indication that RF exposures to workers in the dielectric industry, may result in a greater likelihood of paresthesia. Whether it is transitory or indicative of pathology needs to be determined.

Cancer: As part of the Interphone case-control study, occupational exposures for 747 cases of glioma and meningioma were compared with 1,494 controls.[4] Detailed interviews about previous employment up to two years prior to diagnosis were used to categorize workers into exposure groups based on scientific literature and a review by two industrial hygienists. Occupational exposures that were thought to exceed the exposure limits for the general public (0.08 W/kg) were categorized as "high" exposure and included dielectric heating equipment users, telecommunication antenna technicians and ham radio operators. Only 87 subjects met the criteria for "high exposure" while more than 85% of the cases and controls were classified as "not exposed." After adjusting for socioeconomic status, area of residence (urban or rural), ionizing radiation exposure, smoking history, and age at diagnosis the odds ratio (OR) comparing the high exposure and no exposure was not statistically significant, at OR 1.22 (95% confidence interval [CI] 0.69–2.15). Job titles can be poor surrogates of exposure, particularly as duties and exposure to RF-emitting equipment varies.

Navy personnel, and civilian populations (amateur radio operators and employees of a wireless communication manufacturer) were subjects of retrospective cohort studies examining the risks of mortality and cancer incidence associated with occupational exposures to RF. Szmigielski (1996) determined cancer morbidity in Polish military career personnel enrolled from 1971–1985. Of approximately 128,00 persons each year, about 3,00 (3%) were considered occupationally exposed to RF. Observed/expected ratios (OER) for cancer morbidity, comparing the overall morbidity rates of the exposed personnel to the non-exposed personnel, was 2.07 ($p<0.05$). Higher OERs were found for neoplasms of the alimentary tract, brain tumours and malignancies of the lymphatic organs and haemopoietic system (leukemias and non-Hodgkins lymphoma).

Garland et al. (1990)[27] determined the incidence of leukemia among navy personnel. Information on occupations and service history was obtained from service records between 1974 to 1984 of all active-duty, enlisted white males, for a total of 4.0 million person-years at risk. Leukemia diagnoses from this cohort were obtained from the Naval Health Research Center and standardized incidence rates (SIR) were calculated using the American male population as a reference. The authors calculated SIRs for the naval job titles for which there was at least one case of leukemia, using the total Navy population as a reference. Overall, there were 102 cases of leukemia; the age-adjusted incidence rate amongst navy personnel was similar to the national population, 6.0 and 6.5 per 100,000 person-years, respectively. There were no elevated SIRs as a result of internal comparisons of specific naval job categories; for example, electronic technicians had the highest SIR of only 1.1 (95% CI 0.4–2.5). However, the results may be biased as cases diagnosed outside of the Navy Health Centre were not accounted for.

A cohort of 40,581 Korean War naval veterans was followed for 40 years in the study by Groves et al. (2002).[28] Personnel were divided into high and low exposure groups (thought to have exposures below 1 mW/cm^2) based on consensus assessments of job title by Navy training and operations personnel. Low exposure groups included radar and radio operators stationed below deck; high exposure groups, which included electronics and aviation technicians, had the potential to exceed 100 mW/cm^2, although their exposures were typically below 1 mW/cm^2. However, actual measurements of worksite exposures were not reported. Mortality data for the cohort, taken from Veterans Affairs, was compared to the American Caucasian population; the high and low exposure groups were compared internally. For the high exposure group, in comparison to the general population, there was no increased risk of mortality from brain cancer or leukemia, with a standardized mortality ratio (SMR) of 0.7 (95% CI 0.5–1.0) and 1.14 (95% CI 0.90–1.44), respectively. However, within-cohort comparisons of high exposed versus low exposed, showed a relative risk of mortality from nonlymphocytic leukemia of 1.5 (95% CI 1.0–2.2). The relative risk (RR) for nonlymphocytic leukemia was statistically significant for, aviation electronic technicians, with an RR equal to 2.2 (95% CI 1.3–3.7). The authors noted a limitation to the study of several occupational carcinogenic exposures not being accounted for, including lead, cadmium and chlorinated solvents.

Degrave (2009)[5] followed a cohort of 4,417 Belgian soldiers posted at a North Atlantic Organization (NATO) anti-aircraft unit between 1963 and 1994. The two large radar systems emitted frequencies between 1 and 10 GHz and modeling of the electric field generated by the units estimated exposures to fields of 100 to 500 V/m, with hotspots of 300 and 1300 V/m. By comparison, NATO standards in the 1960s limited exposure to less than 112 V/m. The comparison group was 2,932 Belgian military personnel who served at the same time in the same place in battalions not equipped with radar. The RR obtained by comparison of the two groups for neoplasms was 1.22 (1.03–1.47). The exposed group had an increased risk of death from hemolymphatic cancers (11 cases in the exposed group and 1 in the control group) of RR 7.22 (95% CI 1.09–47.9). The authors noted a potential bias in not accounting for the additional exposures to ionizing radiation from some of the radar equipment (which were replaced in the 1970s).

Using federal licensing data, Milham (1988)[29] identified 67,829 amateur radio operators in the states of California and Washington. A total of 2,485 deaths of this cohort occurred between January 1979 and December 1984, a total of 232,499 person-years at risk, and SMRs were calculated using the American male population as reference. There was a significant increase in the risk of acute myeloid leukemia, SMR 1.76 (95% CI 1.03–2.85). Information on exposure characteristics such as duration of registration as an amateur operator and extent of use, or potential confounding factors, was not available.

Morgan et al. (2000)[30] studied a cohort of employees of Motorola, a large wireless communication products manufacturer. A job exposure matrix was created by expert opinion categorizing job title into exposure groups. High exposure groups included field engineers in cellular phone and paging sectors. Mortality data was taken from the National Death Index, allowing researchers to follow workers if they left employment. A total of 195,775 employees contributed 2.7 million person-years during the 1976 to 1996 period. Unlike the naval and amateur radio operators, 44.0% of the Motorola cohort was female. Compared to the American population, there was no overall increased risk of death. Rate ratios comparing high and low exposure were below or near 1.0 for brain cancer and all lymphomas and leukemias and there was no increased risk associated with exposure for greater than five years. An important limitation of this study was the relatively young age of the cohort, with an average age of 42.8 years at the end of the study period.

The study by Tynes et al. (1996)[21] was unique in that exposure measurements were undertaken and cancer incidence was investigated in women, consisting of a group of 2,619 female telegraph and radio operators on Norwegian merchant ships. Measurements were taken in the radio rooms of three ships. The equipment emits RF with frequencies between 1.6 and 25 MHz. Electric field strength was 20 V/m, with elevated levels of 200 to 1400 V/m near the antenna feed lines. The time that workers spent in these rooms was not reported. Using the Norwegian national population as a reference, there were no increases in the incidence of brain tumours or leukemia. However, an increased SIR for breast cancer was found for workers over the age of fifty of 1.5 (95% CI 1.1–2.0). Though women were followed from 1961 to 1991, the median time at sea was only about three years. The authors also note that operators were exposed to other potential risk factors for breast cancer such as shift work. Data on other known risk factors for breast cancer such as smoking, obesity, and family history were not collected.

Within a cohort of 340 police officers, a cluster of six cases of testicular cancer in police officers who regularly used traffic radar guns was reported and all routinely held the radar gun in their lap in close proximity to their testicles. However, no cause and effect association could be determined with such small numbers.[31] An increased risk of ocular melanoma associated with occupational use of radio communication sets was reported in a case-control study by Stang et al.[32] A total of 118 cases and 475 controls were interviewed. An elevated OR of 3.3 (95% CI 1.2–9.2) was found, although there was no relationship with duration of exposure.

A small study by Lagario et al. (1997)[18] on the mortality of 481 female plastic ware workers found a significant elevated risk for leukemia (SMR 8.0, 95% CI 1.0–28.2) but only based on two cases. The effects of exposure to solvents and vinyl chloride monomer could not be ruled out.

Overall, although there are suggestions of an increased risk of leukemia with RF exposure in some occupations, the inconsistent findings and validity issues concerning exposure ascertainment and small number of cases raise uncertainties about any such association.

Reproductive Outcomes: Military radar technicians have been the focus of most studies evaluating semen parameters and occupational exposure to RF.

The 2004 review of health effects associated with occupational exposure to RF included four cross-sectional studies of the effects of exposure to microwaves and radar among military populations on semen parameters.[2] Three of the studies found reductions in sperm density, with two showing decreases in sperm motility.[33-35] However, either the recruitment strategies were poorly described or there was a substantial non-response rate among these studies.

Grajewski and colleagues (2000)[14] conducted measurements at four plastic sealer (dielectric heater) worksites. Machines emitted frequencies between 12 and 57 MHz and electric field strength ranged from 1.1 to 3.0 V/m. No significant difference was seen between exposed and unexposed workers in sperm density, counts, motility and morphology. However, the study was likely underpowered, with only 12 exposed workers and 34 unexposed. All three reviews of occupational health studies[1-3] suggest further investigation of the effects of RF on fertility, given the known susceptibility of spermatogenesis to heating.

Cardiovascular disease: The possibility of increased risk of cardiovascular disease due to occupational exposure to RF was demonstrated in several early studies from the former Soviet Union. These primarily examined the acute adverse effects of microwave exposure on physiologic measures such as blood pressure and heart rate.[2] Studies of major clinical outcomes have failed to find an association. Three large retrospective cohort studies of American[28] and Belgian military personnel[5] and Motorola workers[30] did not find an increased risk of mortality from heart disease.

Cataracts: The lens of the eye is known to be sensitive to heat compared to other organs; however, epidemiological data linking RF to cataracts is limited. Two case-control studies of American military veterans, both published before 1980 (as cited in Ahlbom, 2004[2]), found no association between the presence of lens opacities and RF exposure from jobs using radar or microwaves. A 1984 Australian study of 53 radio and TV transmitter workers found an increase in prevalence of lens opacities (a precursor to cataracts) compared to 39 "non-radio linemen" from the same communication organization, with 18% prevalence in the transmitter workers compared to 8% in the control group (p-value of 0.043).[36] Antenna emitted frequencies ranged from 558 kHz to 527 MHz. There were no exposure limits for these workers until 1981, and measurements of power density around the work areas varied from 0.08 mW/cm^2 to an extremely high value of 3956 mW/cm^2. However, these studies did not take into account possible differences in exposure to solar radiation, a known risk factor for cataracts.

In summary, most of the epidemiological studies on the association of occupational exposure to RF cancer and cardiovascular disease mortality were negative, based on military cohorts exposed to radar. Exceptions were mixed findings for leukemia. Although there appeared to be an effect of occupational RF exposure on male semen, also in military populations, these results were dubious due to poor study methodology and reporting. The few studies on cataracts showed mixed results. All of these observational studies had problems of poor exposure ascertainment and other potential biases which would affect the outcome.

8.3.5 Discussion on occupational health risks from exposure to RF

Workers in a wide variety of industries are exposed to RF radiation of different frequencies and exposure levels. Current safety guidelines are based on preventing the established acute effects of tissue heating and RF shock. Long-term follow up of workers with acute overexposure may assist in determining whether there are any lasting effects of short duration high-level exposure to RF.

The health effects of chronic occupational exposure to RF have been evaluated in a few studies, but these are often subject to limitations in study design which affects the validity of their findings. The most common limitation is low power, due to the relatively small number of workers studied for relatively rare disease outcomes. Even with large cohort analyses, the quality of exposure assessment is a major limitation. Relying on job titles and lack of exposure measurements are generally a poor proxy of actual exposure. As a result, misclassification of exposure will reduce the statistical significance of a finding, indicating no effect. An additional complication for retrospective studies is that current exposure measurements may not apply to conditions in the past.

Recommendations for improving exposure assessment for prospective cohort studies have been put forward. Breckenkamp et al. (2009)[37] assessed data quality for 21 occupational cohort studies including airport workers, telecommunication technicians, and induction machine operators. Groups were evaluated using four criteria: duration and degree of RF exposure, ease of individual exposure assessment, ability to assemble a cohort of sufficient size and means of follow up. Only three groups were considered viable for the assessment of the effects of long-term RF exposure on health: amateur radio operators, operators of short- and medium-wave transmitters, and RF plastic welders. Because one aspect of the assessment criteria was the size of the industry in Germany, their findings may not be completely transferable to the Canadian or North American context.

Prospective occupational cohort studies would be better suited for the analysis of occupational health effects from RF exposure if cost and technological factors could be addressed. Use of personal RF monitors would improve exposure assessment by taking into account actual exposure of individual workers, rather than potential exposure from a fixed RF source. The development of biological markers as an early indicator of long-term health consequences would reduce the time for follow-up.

Because workers are potentially exposed to higher levels of RF and for longer durations than the general population, occupational health studies may be better able to detect potential health effects. However, generalizability of findings to public exposure to RF remains limited for several reasons: 1) occupational sources of RF exposure, such as radar and industrial equipment, are rarely encountered by the general public and exposure levels are often higher and may involve thermal mechanisms, unlike the lower exposures from public RF sources; 2) workers tend to be healthier than the general population; as such, comparisons of outcomes in a SMR or SIR analyses would result in an underestimation of risk due to the "healthy worker effect"; 3) women are usually underrepresented, and retirees and children are excluded; 4) the effects of RF are highly dependent on frequencies within narrow ranges; industrial EMF applications often use lower frequencies of RF, which have greater penetration into the body; and 5) simultaneous exposures to ELF and other chemical, biological and physical hazards in the workplace are common, and their potential effects should be accounted for in the study design and analysis.

Outcomes of occupational health studies have focused on cancer, particularly brain and blood cancers. Other neurodegenerative diseases such as multiple sclerosis, dementia, and Parkinson's disease remain unexplored. Early disease manifestations of cellular dysfunction should also be considered; however, without an accepted biological mechanism for effects from RF, early manifestations are difficult to identify and measure.

Despite these limitations, further occupational health research has the potential to provide useful data to inform policy on RF exposure for specific occupational groups. Although there are a reasonable number of occupational RF exposure-based studies, there are few epidemiological studies and almost no recent ones evaluating health effects from RF exposure in the workplace. Prospective studies which follow occupational cohorts over time that are exposed to similar exposures and frequency ranges as the general public (such as broadcast workers), may be most informative for alerting the scientific community of possible effects on public health resulting from exposure to RF.

8.4 Appendix A

Current Canadian Occupational Safety Regulations and Standards

In British Columbia, WorkSafeBC is the regulatory authority for compliance with Occupational Health and Safety Regulations, Section 7, Radiation.[38] WorkSafeBC regulations state that the employer must ensure that a worker's exposure to non-ionizing radiation, including RF, must not exceed exposure limits specified for RF in Health Canada's Safety Code 6[23] and Safety Code 25.[39] Three exposure situations, as described in Appendix A, are addressed in guidelines that consider the following scenarios: (a) distances less than 20 cm from the emitting antenna as measured by the Specific Absorption Rate (SAR); (b) induced and contact current limits and (c) environmental exposure assessments in the far field and near field.

(a) At distances less than 20 cm from the emitting antenna: Specific Absorption Rate (SAR)

For a worker standing at a distance of less than 20 cm from the source, the exposure to electromagnetic fields is described in terms of Specific Absorption Rate (SAR), which is the amount of electromagnetic energy absorbed per unit mass of tissue expressed in units of Joules/Kg-sec or Watt/Kg.

SAR represents the degree of **thermal effects** for exposures taking place at distances less than 1 wavelength from the RF source. Thermal effects are predominant in the RF range of **100 kHz–6 GHz** but not significant below 100 kHz.

In summary, whenever a worker is exposed to RF fields at distances shorter than 20 cm in the frequency range 100 kHz–6 GHz, it is recommended to determine the values of the SAR to ensure that the limits of Table 1 below are not exceeded.

Table1. SAR exposure limits for controlled (+) environments

Parts of the body exposed	SAR Limit (W/kg)	Observation
Whole body exposure	0.4	The SAR averaged over the whole body mass.
Head, neck, and trunk	8	The spatial peak SAR for the head, neck and trunk, averaged over any one gram (g) of tissue*.
Limbs	20	The spatial peak SAR in the limbs as averaged over any 10 g of tissue*.

(+) controlled environment means occupational areas, accessible only to workers.

Note: In situations where the determination of SAR is not practical, the measurement of the electric field strength and the magnetic field strength are used as an alternative.

(b) Induced and contact current limits

To minimize the risks of shocks and burns due to induced and contact electric currents generated by electromagnetic fields, a set of limits as shown on Tables 2 and 3 are applied.

The measurement of induced and contact currents is necessary to ensure that the exposure of workers is within these limits.

Table 2. Induced and contact current limits for controlled environments

1 Frequency f (MHz)	2 RMS (*) Induced Current (mA) Through:		3 RMS Contact Current (mA) Hand Grip and Through Each Foot	4 Averaging Time
	Both Feet	Each Foot		
0.003–0.1	2000 f	1000 f	1000 f	1 second
0.1–110	200	100	100	minutes

Note: The frequency f is in MHz

(*) RMS means "root-mean-square." It represents the quadratic mean of time-varying quantities that can take positive or negative values (e.g., sinusoidal functions). For example, if n values I_1, I_2 …In of the induced or contact current are recorded during a period of time, the *rms current* will be:

$$rms\ current = \sqrt{\frac{1}{n}(I_1^2 + I_2^2 + I_3^2 + \cdots . I_n^2)}$$

Table 3. Time-averaged induced and contact current limits for different exposure times for the frequency band 0.1–110 MHz, applicable to controlled environments

Exposure time	Time-averaged induced/contact current (rms) through each foot
≥ 6	100
5	110
4	123
3	141
2	173
1	245
0.5	346
≤ 0.5	350

(c) Environmental exposure assessments in the far field and near field

In the far field, plane wave conditions exist and the electric field strength **E**, the magnetic field strength **H**, and the power density **S** are related by the following equations,

$$E / H = 377, \quad S = E^2/377, \quad S = 377\ H^2$$

where the value **377** represents the **characteristic impedance of free space** in units of Ohms (Ω).

Therefore, in the far field, i.e., at a distance larger than 1 wavelength from the antenna, the measurement of only one of the Quantities **E, H, and S** is enough to obtain the other two.

However, in the near field where plane wave conditions do not exist, the equations above are not valid and power density measurements are meaningless. Therefore, both **E** and **H** must be measured separately in the near field.

The exposure limits for RF workers according to frequency are shown in Table 4.

Table 4. Exposure limits for controlled environments

1 Frequency (MHz)	2 Electric Field Strength rms (V/m)	3 Magnetic Field Strength; rms (A/m)	4 Power Density (W/m^2) [far field only]	5 Averaging Time (min)
0.003–1	600	4.9	--	6
1–10	600/f	4.9/f	--	6
10–30	60	4.9/f	--	6
30–300	60	0.163	10*	6
300–1 500	3.54 $f^{0.5}$	0.0094 $f^{0.5}$	f/30	6
1 500–15 000	137	0.364	50	6
15 000–150 000	137	0.364	50	616 000 / $f^{1.2}$
150 000–300 000	0.354 $f^{0.5}$	9.4 x 10^{-4} $f^{0.5}$	3.33 x 10^{-4} f	616 000 / $f^{1.2}$

* Power density limits are applicable at frequencies greater than 100 MHz.

Notes: Frequency, f, is in MHz; a power density of 10 W/m^2 is equivalent to 1 mW/cm^2; a magnetic field strength of 1 A/m corresponds to 1.257 microtesla (mT) or 12.57 milligauss (mG).

The occupational exposure limits to static magnetic fields are summarized in Table 5 below.[40]

Table 5: Exposure Limits for Controlled Environments

Exposure characteristics	Magnetic flux density B
Exposure of head and of trunk	2 Tesla = 2000 mT
Exposure of limbs	8 Tesla = 8000 mT

Protection of Workers Against RF Fields

The exposure of occupational workers to RF fields must be kept under the limits of Health Canada's RF safety guidelines.

In order to ensure a safe environment for workers around RF sources in the industry, the following rules should be followed:

- Potentially hazardous RF machines and appliances should be appropriately labeled with proper safety instructions.
- Controlled areas around RF sources must be clearly identified by appropriate signs.
- Areas where worker exposure to RF waves is suspected to reach or exceed the recommended limits should be surveyed to determine the existing exposure levels.
- Occupational workers should wear personal RF exposimeters (see description in Section 4) to record the RF exposure (W/m^2) during work in RF environments. RF Exposimeters should also have alarm settings (at exposure limits as in Table 4 or less) to prevent accidental exposures from occurring.

Special Precautionary Measures

Workers wearing implanted devices

Precautions should be taken to ensure that any worker wearing implanted metal and/or electro-medical devices is protected against undesirable effects (induced currents, thermal effects, signal interference) resulting from the presence of RF fields.

Pregnant workers/fetus

Pregnant workers in the RF industry must receive the same protection as the general public to ensure that the fetus will not be exposed to excessive levels of RF fields (i.e., less than 0.5˚C of temperature increase). Therefore, the exposure limits applicable to pregnant workers are the same as those for uncontrolled environments, as shown in Table 6[23] below.

Table 6. Exposure limits for uncontrolled (**) environments

1 Frequency (MHz)	2 Electric Field Strength rms (V/m)	3 Magnetic Field Strength; rms (A/m)	4 Power Density (W/m^2)	5 Averaging Time (min)
0.003–1	280	42.19	--	6
1–10	$280/f$	$2.19/f$	--	6
10–30	28	$2.19/f$	--	6
30–300	28	0.073	2*	6
300–1500	$1.585\ f^{0.5}$	$0.0042\ f^{0.5}$	$f/150$	6
1500–15 000	61.4	0.163	10	6
15 000–150 000	61.4	0.163	10	$616\,000 / f^{1.2}$
150 000–300 000	$0.158\ f^{0.5}$	$4.21\text{x } 10\text{-}4\ f^{0.5}$	$6.67\ 10^{-5}\ f$	$616\,000 / f^{1.2}$

(**) uncontrolled environment means public areas.

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