

## Exposure Level Assessment Study of High Frequency Radiation from Hebron Two-Way Radio Tower

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**Abstract**—A study of the Hebron two-way radio tower in Halhul, which is part of the two-way radio network that links Bethlehem tower in the West Bank to Khan Younes tower in Gaza strip, was conducted. Hebron Tower was built over the highest spot in the region, 1027 m above the sea level. Measurements of signal power was conducted for Hebron tower and compared to various other transmitting towers seen from the area. Analysis reveals that power densities of all towers are invariably safe, and their power densities fall below international safe standards. Results show that power densities from Orange cellular tower, 3500 m away and Marah radio tower, 2350 m away from Hebron tower were indeed higher than all others measured, when all power densities were referenced back to 30 m of their respective tower antenna positions. As far as the Hebron tower is concerned, its height of 111 m provides a relative safe umbrella, from electromagnetic radiation hazard, away from the main radiation beam, over the area below it.

### 1. INTRODUCTION

Scientific evidence about the potential for biological systems and health effects [1,2] from electromagnetic radio frequency radiation is not, generally, unclear or even vague for wise public health decision-makers, as long as research continues to identify what specific exposure conditions may contribute to the environment and human disease. It needs to be reported to decision-makers in a format that is concise, understandable and accurate. Furthermore, conclusive scientific evidence should not be set as the goal required before any interim action, proportional to the weight of evidence, can be taken to limit public exposure to high frequency electromagnetic radiation. Cellular basestations and mobile phones have been known to have potential health hazards, on human health, as far as their electromagnetic radiation and power densities are concerned. Three main effects of electromagnetic radiation on human cells were defined as due to the electric field, magnetic field and specific absorption rate (SAR), specifically generated by cellular phones. While a lot of studies have been conducted and published on Maximum Permissible Exposure (MPE) levels radiated by cellular basestations and SAR levels radiated by mobile phones operating in the 900 MHz/1800 MHz frequency band, a little is known about two-way radio towers serving a wide sector of security and police personnel. Two-way radio systems [3] usually operate in a half-duplex mode, i.e., the operator can talk or listen, but not at the same time. A push-to-talk or press-to-transmit button activates the transmitter; when it is released, the receiver is active. Parameters affecting power density levels from basestations are frequency, initial power, basestation antenna height, antenna radiation angle, radial distance, to name a few. Security personnel usually use two-way radio handsets in “loud speaker” mode and in short talk periods. While the dangers are not that pronounced on the two-way radio handset end, in comparison to the cellular GSM handset, two-way radio tower antennas may pose pronounced danger on human health [4]. Although these towers antennas usually operate with higher power levels than other types of land-mobile antennas, they are normally inaccessible to the public since they must be mounted

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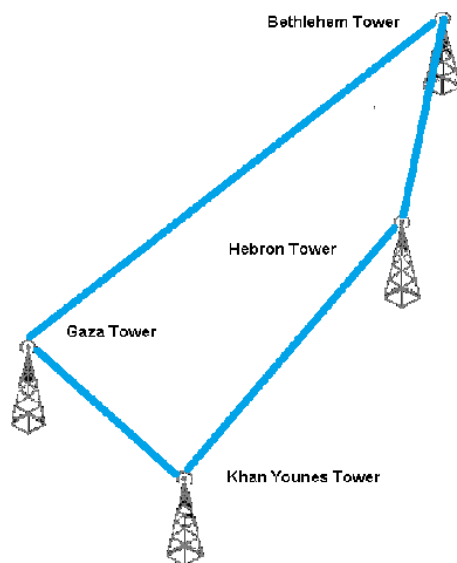
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at significant heights above ground to provide adequate signal coverage. Also, many of these antennas transmit only intermittently. For these reasons, such two-way radio basestation antennas have generally not been of concern with regard to possible hazardous exposure of the public to RF radiation. Studies at rooftop locations have indicated that high-powered paging antennas may increase the potential for exposure to workers or others with access to such sites, for example, maintenance personnel [4]. In comparison to GSM basestations, two-way radio towers radiate in the 400 MHz band. Frequencies in the 400 MHz band are known to have lower propagation path loss than the 900/1800 MHz GSM bands with a lower power density threshold of electromagnetic radiation, if the other mentioned parameters were comparatively made equal. MPE, ruled by the Federal Communications Commission (FCC) guidelines, dictates a maximum exposure of  $f/300 \text{ mW/cm}^2$  ( $f$  is frequency in MHz), over a six-minute average for occupational controlled exposure (i.e., exposure by professional field engineers/technicians) and  $f/1500$  over a period of 30 minutes, for general public/uncontrolled exposure. The dictated limit applies to the transmission frequency range 300–1500 MHz.

## 2. TWO WAY RADIO NETWORK

The Hebron Tower is part of the two-way radio network, which serves the wireless communications needs of the security force in Palestine. It connects Bethlehem two-way radio tower in the West Bank with Khan Younes tower in Gaza Strip. It is approximately 111 m high and situated in the North Western side of Hebron City, in Khirbet Isha, near Halhul. Figure 1 is part of an overall layout of the two-way radio network [5] in Palestine which includes Hebron tower, in the South of West Bank.



**Figure 1.** Part of the Palestinian two way radio network showing Hebron tower's connection to Bethlehem tower and the two other towers in the Gaza Strip.

## 3. EXISTING PUBLIC EXPOSURE STANDARDS

FCC [6] enforces limits for both occupational exposures (in the workplace) and public exposures. The exposure limits are variable according to the frequency (MHz) and exposure duration (6 minutes for occupational/controlled exposure and 30 minutes for general population/uncontrolled exposure). Table 1 shows exposure limits to radiofrequency radiation such as those emitted from AM, FM, television and wireless sources through the air. As an example, at 870 MHz frequency, the general population exposure limit works out as  $0.58 \text{ mW/cm}^2$  (i.e.,  $f_{\text{MHz}}/1500$ ), while for example in the 1800/1900 MHz frequency range, the exposure limit is a fixed  $1.0 \text{ mW/cm}^2$  value. The limits in Table 1 pertain to exposures in the vicinity of transmitting antennas.

**Table 1.** FCC limits for maximum permissible exposure (MPE) [6].

| Limits for Occupational/Controlled Exposure             |                               |                               |                                     |                                 |
|---------------------------------------------------------|-------------------------------|-------------------------------|-------------------------------------|---------------------------------|
| Frequency (MHz)                                         | Electric Field Strength (V/m) | Magnetic Field Strength (A/m) | Power Density (mW/cm <sup>2</sup> ) | Average Exposure Time (minutes) |
| 0.3–3.0                                                 | 614                           | 1.63                          | 100                                 | 6                               |
| 3.0–30                                                  | 1842/ $f$                     | 4.89/ $f$                     | 900/ $f^2$                          | 6                               |
| 30–300                                                  | 61.4                          | 0.163                         | 1.0                                 | 6                               |
| 300–1500                                                | –                             | –                             | $f/300$                             | 6                               |
| 1500–100,000                                            | –                             | –                             | 5                                   | 6                               |
| FCC LIMITS FOR GENERAL POPULATION/UNCONTROLLED EXPOSURE |                               |                               |                                     |                                 |
| Frequency (MHz)                                         | Electric Field Strength (V/m) | Magnetic Field Strength (A/m) | Power Density (mW/cm <sup>2</sup> ) | Average Exposure Time (minutes) |
| 0.3–3.0                                                 | 614                           | 1.63                          | 100                                 | 30                              |
| 3.0–30                                                  | 824/ $f$                      | 2.19/ $f$                     | 180/ $f^2$                          | 30                              |
| 30–300                                                  | 27.5                          | 0.073                         | 0.2                                 | 30                              |
| 300–1500                                                | –                             | –                             | $f/1500$                            | 30                              |
| 1500–100,000                                            | –                             | –                             | 1.0                                 | 30                              |

On the other hand, some countries in the world have established new, low-intensity based exposure standards that respond to studies reporting effects that do not rely on mere heating. Consequently, new exposure guidelines, hundreds or thousands of times lower than those of FCC and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [7], were proposed [8, 9]. Figure 2 [9] shows some of the countries that have lowered their limits, for example, in the cell phone frequency range of 800 MHz to 900 MHz. The levels range from 10  $\mu\text{W}/\text{cm}^2$  in Italy and Russia to 4  $\mu\text{W}/\text{cm}^2$  in Switzerland. In comparison, the United States limits such exposures to 580  $\mu\text{W}/\text{cm}^2$  (at 870 MHz frequency), calculated from the FCC Table 1, whereas the United Kingdom and Canada avoid excessive safety margins by allowing safety levels ten times the proposed FCC level i.e., 5800  $\mu\text{W}/\text{cm}^2$ . Higher frequencies have higher safety limits, so that at 1500 MHz, for example, FCC limit is 1000  $\mu\text{W}/\text{cm}^2$  (i.e.,  $f_{\text{MHz}}/1500 \times 1000$ ), whereas ICNIRP level suggests a relatively lower 750  $\mu\text{W}/\text{cm}^2$  level (i.e.,  $f_{\text{MHz}}/2000 \times 1000$ ). Each individual frequency in the radiofrequency radiation range needs to be calculated. These are presented as reference points only. Emerging scientific evidence has encouraged some countries to respond by adopting planning targets, or interim action levels that are responsive to low-intensity or non-thermal radiofrequency radiation bioeffects and health impacts. It is worth mentioning that the Palestinian Authority enforces 1/250 of the ICNIRP safe level for GSM 900 and GSM 1800/1900 in the frequency range 400 MHz–2000 MHz. Consequently, the resulting power densities are 1.8  $\mu\text{W}/\text{cm}^2$  and 3.6  $\mu\text{W}/\text{cm}^2$ , respectively.

#### 4. ANTENNA FORMULAS [6, 10]

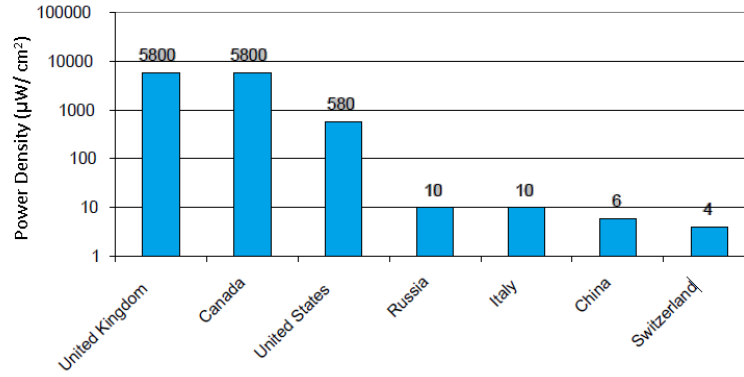
The maximum near-field power density at the antenna surface, the power fed to the antenna, the aperture efficiency and the aperture area are related by Equation (1) [6]:

$$S_{\text{eff}} = \frac{16\eta P}{\pi D^2} \quad (1)$$

where  $\eta$  is the aperture efficiency (typically from 0.5 to 0.75),  $P$  the injected power to the antenna,  $D$  the largest antenna dimension and  $S_{\text{eff}}$  the maximum near field power density at the antenna surface.

The aperture efficiency can be calculated from the following formula:

$$g = \frac{4\pi\eta A}{\lambda^2} \quad (2)$$



**Figure 2.** Some international exposure standards at cell phone frequencies (800–900 MHz).

where  $A$  is the aperture area of the tower antenna,  $g$  the gain and  $\lambda$  the wavelength.

The maximum near-field distance, where radiated power starts degrading with  $1/R$ , in the transition region between near field and far field, can be calculated from Equation (3) [6].  $R$  is the radial distance from antenna centre to the field point.

$$R_{near} = \frac{D^2}{4\lambda} \quad (3)$$

The distance to the beginning of far-field radiation, and pertaining maximum power density, where the radiated power density transits from degrading with  $1/R$ , in the transition region, to  $1/R^2$ , in the far field region, can be worked out from Equations (4) and (5) [6] respectively:

$$R_{far} = \frac{0.6D^2}{\lambda} \quad (4)$$

$$S_{transition} = \frac{S_{near}R_{near}}{R} \quad (5)$$

The power density in the far-field or Fraunhofer region of the antenna pattern which decreases inversely as the square of the distance ( $1/R^2$ ) can hence be estimated from the general equation:

$$p_{d(max)} = \frac{p_g}{4\pi R^2} \quad (6)$$

## 5. THEORETICAL COMPUTATIONS

Theoretical computations for calculating power densities in the far field, at selected ranges, are possible if the specifications of the tower transmitter are known. Specifications for the Hebron tower were readily available. The Hebron Tower Antenna is 111 m above ground level, the antenna gain  $G = 8$  dBi (i.e.,  $g = 6.3$ ),  $f = 423$  MHz,  $D$  (antenna greatest dimension) = 364 cm,  $d$  (cross section diameter) = 4.5 cm, Transmission Power,  $P_{TX} = 15$  W (i.e., 11.76 dB). The cable was of the RG-11 type with attenuation loss 0.115 dB/m. Hence for about 120 m cable length,  $L_{cab}$  was estimated as 14 dB. Connector and other losses were, in addition, estimated as  $L_{con} = 6$  dB. Hence power at the antenna port works out as:

$$P = P_{TX} - L_{cab} - L_{con} \quad (7)$$

or 21.76 dBm (i.e., 150 mW). The wavelength works out as  $\lambda = 71.1$  cm. From Equation (3), the extent of the near-field distance,  $R_{near}$ , is calculated as 4.66 m. The aperture efficiency,  $\eta$ , on the other hand, can be calculated from Equation (2) and knowledge of physical dimensions of the antenna. Accordingly, the cylindrical surface area of the dipole antenna works out as  $\pi dD = 5.15 \times 10^3$  cm<sup>2</sup>, and the effective area,  $\eta A$ , calculated from the mentioned equation is  $2.53 \times 10^3$  cm<sup>2</sup>. Hence,  $\eta = \eta A/A = 0.49$ .

The maximum near-field power density can now be calculated using Equation (1).  $S_{eff}$ , hence, works out as 28.25 mW/m<sup>2</sup>, which is constant and equals  $S_{near}$ , throughout the near-field distance

$R_{near} = 4.66$  m, from the antenna surface. The distance to the beginning of far-field region can be calculated from Equation (4) as  $R_{far} = 11.18$  m. The transition region which extends from  $R_{near}$  to  $R_{far}$  is where the power density degrades with  $1/R$ . Hence, the maximum main beam power density in the far field can be calculated from Equation (5) as  $P_{dmax} = 11.775$  mW/m<sup>2</sup> (i.e.,  $28.25 \times 4.66/11.18$ ). At 30 m, in the far field, the power density works out, from Equation (6), as  $0.0835$  mW/m<sup>2</sup> (i.e.,  $150$  mW  $\times 6.3/(4\pi \times 30^2)$ ), and  $0.25$   $\mu$ W/m<sup>2</sup> at 550 m (i.e.,  $150$  mW  $\times 6.3/(4\pi \times 550^2)$ ).

## 6. FIELD MEASUREMENTS

Signal power measurements were recorded, utilizing a handheld realtime spectrum analyzer of the type SPECTRAN HF60100 V4 [11, 12] with typical accuracy of 1 dB and frequency range 1 MHz up to 9.4 GHz, suitable for outdoor field measurements. The analyser has a number of useful characteristics. It has a real-time, very fast, digital signal processing engine capable of processing the entire bandwidth, utilizing Fast Fourier transform algorithm, with no gaps. It has an analogue to digital converter (ADC) capable of digitising the entire bandwidth of the pass band. It also has a sufficient capture memory to enable continuous acquisition over the desired measurement period. The SPECTRAN analyzer is a smart device where frequency bands are automatically set and saved by numerically pressing a key representing, one of the following numeric blocks:

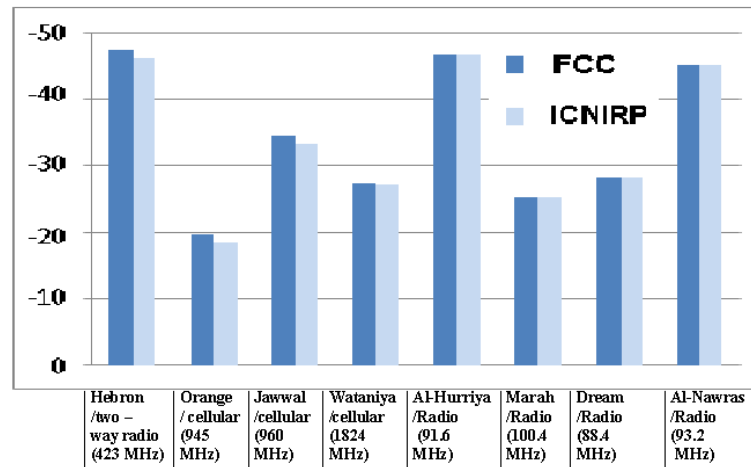
- 1 = Tetra (380–400 MHz)
- 2 = ISM434 (433–434.8 MHz)
- 3 = LTE800 (780–862 MHz)
- 4 = ISM868 (868–870 MHz)
- 5 = GSM900 (921.2–959.6 MHz/cell towers, no cell phones)
- 6 = GSM1800 (1800–1880 MHz/cell towers, no cell phones)
- 7 = UMTS (2110–2170 MHz/cell towers, no cell phones)
- 8 = WLAN (2400–2490 MHz/cell towers, no cell phones)
- 9 = LTE2.6 (2500–2690 MHz)
- 0 = DECT-analyzer (1880–1900 MHz) (Measurement of digital portable DECT phones)

We knew the center frequency of each transmitting tower. We set the analyzer to the center frequency of the selected tower then initially chose a start and stop frequency around it for a general wide span. After having an initial visualization about the spectrum, we adjusted the frequency range to a conveniently narrower span, for a final power density measurement. It is worth mentioning that a large frequency range will badly squeeze the display horizontally (in the  $X$  axis) and thus significantly reduce measurement accuracy. By narrowing the frequency span, one would be able to sweep range more precisely and see more details. A large frequency span is thus mostly useful for a broad overview, not for exact measurements. To eliminate interference, harmonics and achieve faster sweeps, a small frequency span below 100 MHz was used. We used a resolution bandwidth setting of 3 MHz and a sweep time of 1 ms. When 1 MHz is needed for weaker signals, the sweep takes relatively longer time, but the display will look more precise. In general, the higher the sweep time setting is, the more precise the measurement is, at the cost of more time consuming. With regard to the video bandwidth, the highest possible video filter setting was used, when dealing with weak signals. In such a case, with low video filtering (say 100 KHz), the display of the received signal could become less meaningful as the filter excessively smoothened the signal. Furthermore, we took the electrical polarization into consideration. The radio towers transmitted in vertical polarization while the mobile towers transmitted in 45° orientation. Accordingly, the handheld antenna was best adjusted and kept in orientation and direction for maximum power density measurement. The device is provided with a calibration set, composed of an attenuator, a cable and a 5 dB-gain log periodic antenna. We took measurements from the highest house roof, in the area, 80 meters away, from the Hebron tower but also took measurements of various transmitting towers at various frequencies and further distances, in order to compare their power densities with FCC and ICNIRP safe thresholds at their transmitting frequencies. We verified all distances using “Google Earth” and available satellite maps of Hebron North and measured frequencies,

received power and power densities of all transmitting towers, as shown in Table 2. The calibrated logarithmic antenna helped boosting received signals with very low power amplitude, from relatively far towers, with distances ranging from 550 m to 3500 m. The SPECTRAN analyser has capabilities to measure electric field and power densities in the desired units. One can visualize the frequency spectrum of the measured signal within a bandwidth range limited by the selected start and stop frequencies. We selected an appropriate window for each measured tower signal so that the frequency limits of the whole spectrum are either negligible or fall just at the noise level. We could see each tower from the Hebron tower measurement site and aimed directly at each tower, seeking maximum obtained average measured power density. Figure 3 compares, for demonstration convenience, logarithmic power density ratios of all transmitting towers with respect to the safe thresholds as provided by FCC and ICNIRP international guidelines. Each measured transmitting tower power density was worked back to a standard 30 m distance from its respective tower. This is done by comparing power density values with the inverse of each relative square line-of-sight distance. In the case of Hebron tower, although we took measurements at 30 m and 80 m distances, we considered the power density measurements taken at 550 m distance then referenced it back to 30 m. Measurement was thus taken in the vicinity of the main lobe and not in the proximity of the high tower base, under the main radiation lobe.

**Table 2.** Signal power measurements of various transmitting towers.

| Tower/<br>type           | Frequency<br>MHz | Distance<br>m | ( $P_{d\_FCC}$ )<br>FCC Safe<br>public<br>threshold<br>$mW/m^2$ | ( $P_{d\_ICNIRP}$ )<br>ICNIRP<br>Safe<br>public<br>threshold<br>$mW/m^2$ | Measured<br>power<br>dBm | Measured<br>power<br>density<br>$\mu W/m^2$ | ( $P_{d\_30\ m}$ )<br>Calculated<br>power<br>density@30 m<br>$mW/m^2$ |
|--------------------------|------------------|---------------|-----------------------------------------------------------------|--------------------------------------------------------------------------|--------------------------|---------------------------------------------|-----------------------------------------------------------------------|
| Hebron/<br>two-way radio | 423              | 30            | 2,820                                                           | 2,115                                                                    | -45                      | 0.32                                        | $0.32 \times 10^{-3}$                                                 |
| Hebron/<br>two-way radio | 423              | 80            | 2,820                                                           | 2,115                                                                    | -50                      | 0.09                                        | $0.09 \times 10^{-3}$                                                 |
| Hebron/<br>two-way radio | 423              | 550           | 2,820                                                           | 2,115                                                                    | -47                      | 0.15                                        | $50.4 \times 10^{-3}$                                                 |
| Orange/<br>cellular      | 945              | 3500          | 6,300                                                           | 4,725                                                                    | -38                      | 5                                           | $68,055 \times 10^{-3}$                                               |
| Jawal/<br>cellular       | 960              | 1000          | 6,400                                                           | 4,800                                                                    | -42                      | 2                                           | $2,222 \times 10^{-3}$                                                |
| Wataniya/<br>cellular    | 1824             | 1800          | 10,000                                                          | 9,120                                                                    | -45                      | 5                                           | $18,000 \times 10^{-3}$                                               |
| Al-Hurriya/<br>Radio     | 91.6             | 2350          | 2,000                                                           | 2,000                                                                    | -44                      | 0.007                                       | $42.95 \times 10^{-3}$                                                |
| Marah/<br>Radio          | 100.4            | 2350          | 2,000                                                           | 2,000                                                                    | -26                      | 1                                           | $6,136 \times 10^{-3}$                                                |
| Dream/<br>Radio          | 88.4             | 2350          | 2,000                                                           | 2,000                                                                    | -35                      | 0.45                                        | $3,125 \times 10^{-3}$                                                |
| Al-Nawras/<br>Radio      | 93.2             | 2350          | 2,000                                                           | 2,000                                                                    | -45                      | 0.01                                        | $61.36 \times 10^{-3}$                                                |



**Figure 3.**  $10 \log(Pd_{30m}/Pd_{safe} \text{ threshold})$  in dB vs. transmitting towers where the safe threshold power density is referenced to FCC and ICNIRP respectively.

## 7. DISCUSSION

A study of the power density calculation and measurement of the two-way radio signal from Hebron tower was conducted. Results were compared with measured data from other cellular and radio towers in the area. Comparison with FCC and ICNIRP standards reveals that power densities at referenced 30 m distance away from the antenna positions of the various towers, transmitting at different frequencies, are relatively but invariably safe. Signals from towers transmitting longer distances such as Orange cellular tower and Marah radio tower had relatively higher power densities than other transmitting towers, including Hebron tower. FCC guidelines dictate an average time of 30 minute exposure to electromagnetic radiation safe limits for the public and astonishingly no time periods for exposure to less than those limits. Hence the longer term effects of lower power density levels on human health are possible but not confirmed. It is worth mentioning that grounding appears to be a different kind of risk that Hebron tower poses, despite its relatively lowest power density level amongst all other towers. Mesh grounding with ground inserted rods and bonding along the tower is the genuine solution to resolve phase to phase power breakdown problems. With regard to the calculated and measured power density at 30 m range from Hebron tower, result values were compared favourably. Pertaining theoretical density worked out as  $83.5 \times 10^{-3} \text{ mW/m}^2$  while the measured one worked out as  $50.4 \times 10^{-3} \text{ mW/m}^2$ , despite possible system and personal errors.

## 8. CONCUSSION

More studies and measurements need be conducted and continuously monitored to enable control action of possible electromagnetic radiation hazards from towers. We conclude that unlike Orange, Jawwal and Wataniya appear to commit to 1/250 of the dictated ICNIRP safe standards, as enforced by the Palestinian Ministry of Environment. Results have shown that power densities referenced to 30 m from Jawwal and Wataniya towers are indeed less than 1/2800 and 1/500 of ICNIRP safe level, respectively. More notably, Hebron tower appeared to be the safest amongst all towers, compared to each of their power density safety threshold.

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