Health Hazards due to Radiation from Mobile Phone Towers

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Abstract: We are all living in a sea of invisible electromagnetic radiation (EMR) pollution because of the constant exposure of humans to EMR in the very high frequency and ultra-high frequency range from both natural and man-made sources, such as thunderstorm activity, the earth's magnetic field, mobile phone towers, television transmitters, high voltage electric lines, mobile phones, computers, laptops, microwave ovens, etc. The authors of this paper use mathematical modeling to determine the amount of energy absorbed by human body tissues in terms of specific absorption rate (SAR) in an effort to educate the general public and society, particularly those who live close to mobile phone transmitter towers, about the invisible EMR and its detrimental effects on humans. The SAR standard values are also provided by the global system mobile (GSM) and other international cell phone standards e.g the Inter-national Commission on Non-Ionizing Radiation Protection (ICNIRP), World Health Organization (WHO), Institute of Electrical and Electronics Engineers (IEEE), Federal Communications Commission (FCC), Department of Telecommunications (DOT) International Telecommunication Union (ITU) etc. In this work, the calculated SAR values obtained from the modeling approach are compared with the permissible limits defined by these national and international agencies. The results show that the computed SAR values are within the safety limits recommended by the respective authorities.

Keywords: *Non-Ionizing Radiation (NIR), Electromagnetic Radiation (EMR), Specific Absorption Rate (SAR).*

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I. INTRODUCTION

The advent of fifth-generation (5G) mobile networks, which promise extremely fast data speeds, reduced latency, and improved connectivity, has been brought about by the rapid development of cordless communication technologies. In contrast to its predecessors, 5G uses higher frequencies, such as extremely high frequency waves (24 GHz to 100 GHz), which necessitates a dense installation of antennas and small-cell base stations. Non-ionizing electromagnetic radiation (EMR) levels in the environment rise as a result. In contrast to ionizing radiation (such X-rays or $\gamma -$ rays), Non-ionizing radiation lacks the energy necessary to liberate tightly bound electrons from atoms or molecules. Concerns over possible negative health effects, however, have grown as a result of its extensive and persistent exposure. Studies have connected biological effects such tissue heating, oxidative stress, DNA damage, and alterations in cellular function to non-charged radiation, especially in the radiofrequency (RF) spectrum employed by mobile communication systems. The International Agency for Research on Cancer (IARC) has categorized radiofrequency radiation as potentially carcinogenic to humans (Group 2B), while scientific consensus is still unclear.

Understanding the effects of long-term exposure is crucial since 5G technology is predicted to greatly increase the volume and frequency of RF radiation. The rate of body tissue absorption in human tissues and the possibility of both thermal and non-thermal impacts have come into sharper focus as a result, particularly for vulnerable groups including children, the elderly, and people with underlying medical disorders.

By examining the most recent scientific research and assessing exposure hazards in light of current safety regulations, this report attempts to investigate the likely health effects of Non-ionizing radiation from 5G mobile towers. Research on the possible biological and health impacts of Non-ionizing radiation, especially in the radiofrequency (RF) and millimeter wave (MMW) bands, has increased as a result of the growing deployment of 5G infrastructure. Numerous studies have documented both thermal and non-thermal biological reactions to extended

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radiofrequency exposure, despite the fact that non-ionizing radiation lacks the energy to directly harm DNA.

- *SAR and Thermal Effects:*

The body's rate of absorption of radiofrequency energy is measured by the SAR. International agencies like the International Commission on Non-Ionizing Radiation Protection (ICNIRP) consider it as a crucial metric to set safety thresholds. According to research by Khurana et al. (2010), because 5G frequencies typically have a short penetration depth but a high energy deposition, high SAR levels may result in tissue heating, especially in the skin and superficial organs.

- *The Effect of Non-Thermal Biology*

Several studies suggest that non-thermal effects of radiofrequency radiation may be more significant than previously thought. Pall (2018) work suggests that oxidative damage may arise via procedures such as simulating voltage-gated calcium channels (VGCC). DNA breakage and an increased risk of cancer development. Similarly, in experimental models, Panagopoulos et al. (2015) showed that even low-intensity radiofrequency exposure could result in DNA breakage and reduced reproductive potential.

- *Exposure to millimeter waves (5G-Specific):*

Millimeter waves (MMWs) with frequencies higher than 24 GHz are used in the 5G network. Because these waves are largely absorbed by the layers of skin, there are worries regarding potential effects on the eyes and skin. Russell (2018) examined the biological effects of MMWs and highlighted possible dangers include eye injury, skin irritation, and immune system disruption.

- *Public health and epidemiological research:*

Although it did not particularly address 5G, the International Agency for Research on Cancer (IARC)-coordinated Interphone StudyGroup (2010) discovered a statistically significant increase in glioma risk among heavy mobile phone users. The IARC's classification of RF-EMR as probably carcinogenic was supported by another extensive study conducted by Hardell and Carlberg (2015), which examined the prevalence of brain tumors and discovered a link with increased mobile phone usage over time.

- *Current Safety Requirements and Remarks*

Guidelines for reducing electromagnetic field exposure were updated by the ICNIRP (2020), which established limits for both whole-body and localized SAR. These restrictions, according to experts like Stilwell et al. (2021), do not sufficiently take into consideration cumulative, long-term, and low-intensity exposures, especially from dense 5G infrastructure. This review draws attention to the continuous discussion and developing knowledge regarding the health impacts of RF-EMR, particularly in light of 5G. Within defined exposure limits, some studies predict negligible health risks; yet, an increasing amount of research points to possible biological and epidemiological issues that call for preventative measures and additional long-term research.

- *Field Measurement of RF-EMR*

Field tests were carried out in specific urban areas with 5G towers operating in the 26 GHz and 3.5 GHz frequency ranges. Using broadband isotropic EMF probes and a calibrated spectrum analyzer (such as the Narda SRM-3006), measurements were made at different distances (5 - 500 m) from the base station. To assess exposure variability in the actual world, environmental factors such line-of-sight blockage, antenna direction, and time of day were noted. In accordance with ICNIRP recommendations, data were averaged over 6-minute intervals.

- *Current Research on Health Impacts*

Alfonso Balmori's Systematic Review (2022), 38 research involving people who live close to mobile phone base stations were examined in a thorough assessment. Results showed adverse health impacts such as cancer, radiofrequency illness, and alterations in biochemical markers were recorded in 73.6% of these studies. Remarkably, 76.9% of research on cancer found a correlation with base station proximity. 5G Exposure Case Reports (2023), In a number of case studies, people reported experiencing symptoms like headaches, insomnia, and skin problems soon after being exposed to 5G base stations. Although a causal relationship has not been proven, these studies raise the possibility of a connection between 5G radiation and specific health symptoms. Review Commissioned by the WHO (2024), The World Health Organization commissioned a systematic analysis that examined more than 5,000 research and found no concrete evidence that using a mobile phone or being close to a base station increases the risk of developing brain or other head and neck malignancies. According to the review, there is no proof that radio waves from wireless technology pose a health risk.

II. METHODOLOGY

There are two main parts used: (i) a review of the literature and synthesis of databases; (ii) SARmodeling utilized mathematical models.

A. *Review of Literature and Synthesis of Data:*

To assess the current scientific evidence about the health risks associated with non-ionizing radiofrequency radiation, a comprehensive assessment of the literature was carried out. We used keywords like “5G radiation,” “RF-EMR health effects,” “SAR,” “millimeter wave exposure,” and “non-ionizing radiation” to find peer-reviewed articles from Scopus, PubMed, ScienceDirect, and IEEE Xplore. Studies published between 2010 and 2024 that concentrated on biological, epidemiological, and theoretical models of radiofrequency radiation met the inclusion criteria. To guarantee rigor and reproducibility, review procedureswerein compliance withPRISMA principles.

B. *SAR and Electric Field Modeling:*

- *Theoretical Analysis:*

Previously published theoretical and experimental data on SAR measurements and tissue-specific heating were reviewed in order to supplement the literature analysis. These comprised: mathematical representations of how microwave and radiofrequency radiation interact with human tissues.

➢ *EMR'S Interaction with Human Health:*

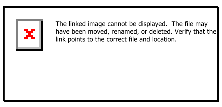
A complex interplay of numerous factors determines how RF/MW radiation interacts with living systems, including humans. The EMF within the biological body is what causes biological reactions. The electrical characteristics of living systems are used to calculate the quantity of radiation that is reflected, transmitted, and absorbed for a specific exposure field. The radiator's near-field, polarization, intensity, and frequency all define the exposure field. The frequency of the electromagnetic source determines how biological material interacts with it (Moulder and Foster,1995). Both macroscopic and microscopic (molecular, cellular) levels might be taken into consideration. Two fundamental mechanisms control interactions at the molecular level: field-induced rotations of polar molecules at higher RF and microwave frequencies, and space charge polarization at lower RF (Health Aspects, Part I and II, 1977, 1978). Traveling charge carriers, or ions, are the cause of the space charge polarization, and the applied field has an impact on the ions' entire motion. When exposed to an electric field, polar molecules—that is, molecules with an unequal spatial distribution of charges, including proteins and water—experience a torque. These two mechanisms are both relaxation-related. Only a small percentage of charges or molecules are truly impacted by the field in moderate fields. The movements are impeded by the thermal motion of charges and molecules, and the kinetic energy is transformed into thermal energy. These interactions result in the conversion of electromagnetic energy into molecular kinetic energy and then thermal energy, which raises body temperature or causes heating (Mclntosh et al., 2005).

The biological tissues of the human body are impacted when electromagnetic radiation from transmission towers penetrates the body. Since the electric field radiates outward from the tower in all directions, its strength is determined by Polk (1996) and is influenced by the distance from the tower.

$$\frac{\mathrm{P}}{4\pi \mathrm{r}^2} = \frac{\mathrm{E}_0^2 \epsilon_0 \mathrm{c}}{2}$$

where ϵ_0 is the permittivity of open space and c is the speed of light or EMR.

$$\mathrm{E}_0 = \frac{P}{(2p^2 \in_0 c)^{\frac{1}{2}}}$$



As a result, the distance from the transmission towers is inversely proportional to the electric field surrounding them. Polk (1996) provides the electric field at different depth within the human body caused by the incident electric field on the body's surface.

$$E_z = E_0\, exp^{\left|-\frac{z}{d}\right|}$$

where d is the skin depth, or the distance at which the field at the boundary is reduced to times of its initial value. It is determined by the radiation frequency for biological bodies, which is provided by

$$d = \frac{1}{q\omega}$$

$$q = \left[\frac{\mu\epsilon\{(1+p^2)^{\frac{1}{2}} - 1\}}{2}\right]^{\frac{1}{2}}$$

$$p = \frac{\sigma}{\omega\varepsilon}$$

where ε is the tissue material's permittivity and ω is the radiation's radian frequency. μ is the tissue material's permeability. σ is the tissue material's conductivity. The electric field within the tissues of the human body can be measured at depths using the mathematical formula above.

➢ *Specific Absorption Rate (SAR):*

It is defined as the rate of change of the incremental energy (dw) absorbed or dissipated is an incremental mass (dm) contained in a volume element (dv) of a given density (ρ)

$$SAR = \frac{d}{dt}\left(\frac{dw}{dm}\right) = \frac{d}{dt}\left(\frac{dw}{\rho dv}\right)$$

If electromagnetic field is sinusoidal

$$SAR = \frac{\sigma E_i^2}{\rho}$$

Where σ is conductivity of the human tissues, E_i is induced electric field inside human body tissues; ρ is the density of tissues materials

Advances in research and policy were made possible by this methodical, multidisciplinary approach, which guaranteed a fair and fact-based understanding of the biological effects of non-ionizing radiation. The observation tables, which were arranged according to the type of radiation, biological systems impacted, observed effects, and study findings, dealt with the health impacts of non-charged radiation. An organized summary of pertinent experimental and epidemiological findings is given by these tables.

III. OBSERVATIONS:

The observation tables for dielectric properties and SAR values of human tissues at 28 GHz, 37 GHz, and 60 GHz—three key frequencies used or proposed for 5G mmWave deployment. These values are synthesized from standard databases like the IT'IS Foundation and calculated values of SAR using mathematical modelling.

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Table 1: Dielectric Properties of Human Tissues at 28 GHz, 37 GHz, and 60 GHz

Tissue Type	Relative Permittivity (ε_r)	Conductivity (σ) [S/m]	Penetration Depth (mm)	Frequency
Skin (Dry)	10.9	14.4	0.41	28 GHz
	9.7	20.1	0.3	37 GHz
	8.4	36.2	0.23	60 GHz
Muscle	12.4	11.8	0.35	28 GHz
	10.3	18.7	0.26	37 GHz
	8.6	34.1	0.19	60 GHz
Eye (Cornea)	14.2	15.1	0.22	28 GHz
	11.8	22.5	0.17	37 GHz
	10.1	38.8	0.12	60 GHz
Fat	2.7	2.1	1.2	28 GHz
	2.4	3.8	0.98	37 GHz
	2.1	6.7	0.7	60 GHz
Bone (Cortical)	5	3.5	0.8	28 GHz
	4.3	5.7	0.64	37 GHz
	3.6	10.2	0.45	60 GHz

Data adapted from IT'IS Foundation and peer-reviewed RF tissue studies (2020–2023)

Table 2: Simulated Peak Local SAR in Human Tissues at 28 GHz, 37 GHzand 60 GHz

Tissue Type	SAR (W/kg)@28 GHz	SAR (W/kg)@37 GHz	SAR (W/kg)@60 GHz	Exposure Condition
Skin(Forehead)	4.55	6.82	10.71	10 W/m², normal incidence
Eye (Cornea)	6.88	9.31	14.92	10 W/m², frontal exposure
Muscle (Arm)	2.21	3.42	5.67	10 W/m², inclined incidence
Fat(Abdomen)	1.57	2.71	4.81	10 W/m², oblique angle
Bone (Skull)	0.93	1.42	2.39	10 W/m², partial exposure

Table 3: Summary for Skin: Key Parameters at 28, 37 and 60 GHz

Frequency	Skin Conductivity (σ)	Penetration Depth	Surface SAR (W/kg) (est.) @ 10 V/m	Density (ρ)
28 GHz	14.4 S/m	0.41 mm	~1.31 W/kg	1100 kg/m³
37 GHz	20.1 S/m	0.30 mm	~1.83 W/kg	1100 kg/m³
60 GHz	36.2 S/m	0.23 mm	~3.30 W/kg	1100 kg/m³

Assuming uniform field of 10 V/m and ε_r ~ 10.9 → 8.4 (decreasing with frequency)Actual SAR depends on incident field strength and exposure geometry

Table 4: Variation of Induced Electric Field with distance from tower at 20 W

Sr. No.	Transmitter power output (Watt)	Distance from towers (m)	Incident Electric Field (V/m)	Skin depth (mm)	Induced Electric Field (V/m)				
					1mm	2mm	3mm	4mm	5mm
1	20	10	3.464	0.23	0.045	0.0006	7.5E-06	9.7E-08	1.3E-09
2	20	20	1.732	0.23	0.022	0.0003	3.7E-06	4.8E-08	6.3E-10
3	20	30	1.155	0.23	0.015	0.0002	2.5E-06	3.2E-08	4.2E-10
4	20	40	0.866	0.23	0.011	0.0001	1.9E-06	2.4E-08	3.1E-10
5	20	50	0.693	0.23	0.009	0.0001	1.5E-06	1.9E-08	2.5E-10
6	20	60	0.577	0.23	0.007	1E-04	1.2E-06	1.6E-08	2.1E-10
7	20	70	0.495	0.23	0.006	8E-05	1.1E-06	1.4E-08	1.8E-10
8	20	80	0.433	0.23	0.006	7E-05	9.4E-07	1.2E-08	1.6E-10

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9	20	90	0.385	0.23	0.005	6E-05	8.3E-07	1.1E-08	1.4E-10
10	20	100	0.346	0.23	0.004	6E-05	7.5E-07	9.7E-09	1.3E-10

Table 5: Variation of Induced Electric Field with distance from tower at 316 W

Sr. No.	Transmitter power output (Watt)	Distance from tower (m)	Incident Electric Field (V/m)	Skin depth (mm)	Induced Electric Field (V/m)				
					1mm	2mm	3mm	4mm	5mm
1	316	10	13.770	0.5	1.864	0.2522	0.0341	0.0046	0.0006
2	316	20	6.885	0.5	0.932	0.1261	0.0171	0.0023	0.0003
3	316	30	4.590	0.5	0.621	0.0841	0.0114	0.0015	0.0002
4	316	40	3.442	0.5	0.466	0.0630	0.0085	0.0012	0.0002
5	316	50	2.754	0.5	0.373	0.0504	0.0068	0.0009	0.0001
6	316	60	2.295	0.5	0.311	0.0420	0.0057	0.0008	0.0001
7	316	70	1.967	0.5	0.266	0.0360	0.0049	0.0007	0.0001
8	316	80	1.721	0.5	0.233	0.0315	0.0043	0.0006	0.0001
9	316	90	1.530	0.5	0.207	0.0280	0.0038	0.0005	0.0001
10	316	100	1.377	0.5	0.186	0.0252	0.0034	0.0005	0.0001

Table 6: Variation of Specific Absorption Ratio with Distance from Tower at 20W

Sr. No.	Transmitter power output (Watt)	Distance from tower (d)	Incident Electric Field (V/m)	Skin depth (mm)	SAR(W/Kg)					
					Skin surface	1mm	2mm	3mm	4mm	5mm
1	20	10	3.464	0.23	0.395	4.6E-05	7.6E-09	1.3E-12	2.1E-16	3.6E-20
2	20	20	1.732	0.23	0.099	1.1E-05	1.9E-09	3.2E-13	5.3E-17	8.9E-21
3	20	30	1.155	0.23	0.044	5.1E-06	8.5E-10	1.4E-13	2.4E-17	4.0E-21
4	20	40	0.866	0.23	0.025	2.9E-06	4.8E-10	8.0E-14	1.3E-17	2.2E-21
5	20	50	0.693	0.23	0.016	1.8E-06	3.1E-10	5.1E-14	8.5E-18	1.4E-21
6	20	60	0.577	0.23	0.011	1.3E-06	2.1E-10	3.5E-14	5.9E-18	9.9E-22
7	20	70	0.495	0.23	0.008	9.3E-07	1.6E-10	2.6E-14	4.4E-18	7.3E-22
8	20	80	0.433	0.23	0.006	7.1E-07	1.2E-10	2.0E-14	3.3E-18	5.6E-22
9	20	90	0.385	0.23	0.005	5.6E-07	9.4E-11	1.6E-14	2.6E-18	4.4E-22
10	20	100	0.346	0.23	0.004	4.6E-07	7.6E-11	1.3E-14	2.1E-18	3.6E-22

Table7: Variation of Specific Absorption Ratio with Distance from Tower at 316W

S. No.	Transmitter power output (Watt)	Distance from tower (d)	Incident Electric Field (V/m)	Skin depth (mm)	SAR(W/kg)					
					Skin surface	1mm	2mm	3mm	4mm	5mm
1	316	10	13.770	0.23	**6.240**	0.0789	0.00145	2.6E-05	4.8E-07	8.9E-09
2	316	20	6.885	0.23	**1.560**	0.0197	0.00036	6.6E-06	1.2E-07	2.2E-09
3	316	30	4.590	0.23	0.693	0.0088	0.00016	2.9E-06	5.4E-08	9.9E-10
4	316	40	3.442	0.23	0.390	0.0049	0.00009	1.7E-06	3.0E-08	5.6E-10
5	316	50	2.754	0.23	0.250	0.0032	0.00006	1.1E-06	1.9E-08	3.6E-10
6	316	60	2.295	0.23	0.173	0.0022	0.00004	7.4E-07	1.3E-08	2.5E-10
7	316	70	1.967	0.23	0.127	0.0016	0.00003	5.4E-07	9.9E-09	1.8E-10
8	316	80	1.721	0.23	0.097	0.0012	0.00002	4.1E-07	7.6E-09	1.4E-10
9	316	90	1.530	0.23	0.077	0.0010	0.00002	3.3E-07	6.0E-09	1.1E-10

10	316	100	1.377	0.23	0.062	0.0008	0.00001	2.6E-07	4.8E-09	8.9E-11

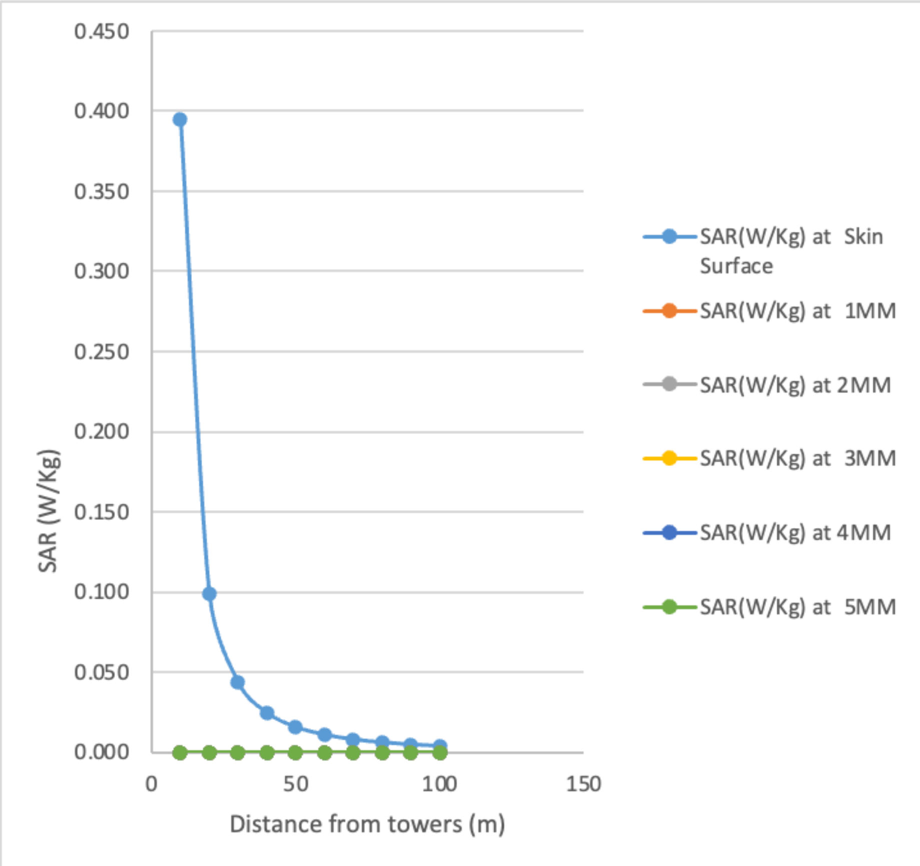

Fig. 1 Variation of SAR with Distances from Towers at 20 W

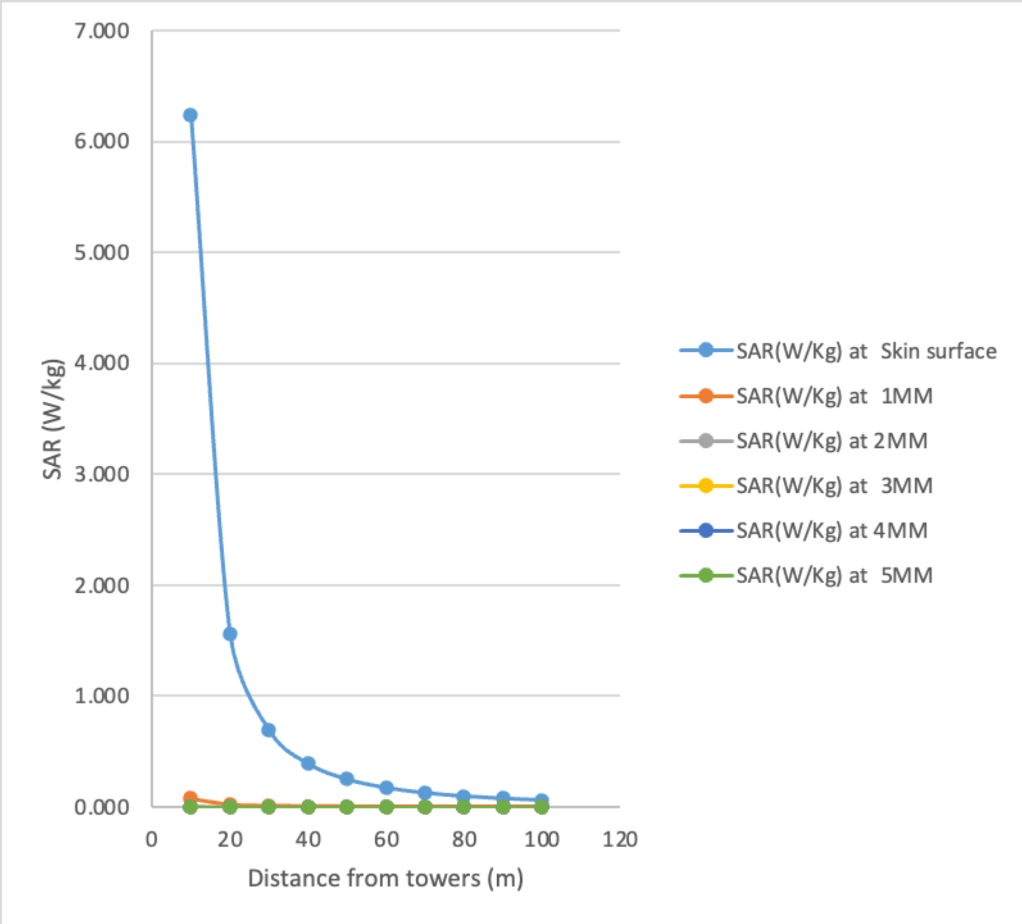

Fig. 2 Variation of SAR with Distances from towers at 316W

IV. RESULT AND DISCUSSIONS

Tables containing the determined induced electric field and SAR values for human skin at a frequency of 60 GHz are provided, as are illustrations of these values. Both SAR and the generated electric field show critical levels at the human skin's surface that may be detrimental to health. The ICNIRP and other national and international authorities have set safety limits that are higher than these values. In order to protect workers and the general public from the thermal effects of RF radiation exposure, ICNIRP establishes exposure limits. In particular, the ICNIRP advises a maximum SAR of 2.0 W/kg, averaged across 10 grams of tissue, for cell phones. The possible health effects of RF radiation exposure have also been evaluated by agencies e.g. IARC and WHO. Because of the possible health concerns connected with both thermal and non-thermal impacts, they stress the necessity of ongoing monitoring and research on the long-term effects of such exposure, especially at frequencies like 60 GHz. The main issue with the very well-understood thermal effects of 5G radiation at 60 GHz is localized skin heating. This happens because the skin's surface absorbs a lot of energy, which may cause thermal damage if exposure goes beyond safe bounds. However, further scope of the research is needed to completely understand the non-thermal consequences of 60 GHz radiation, such as electromagnetic hypersensitivity and the possibility of long-term health hazards (including cancer and genetic damage). Although there are theories regarding these dangers, conclusive connections have not yet been made. Regulatory agencies have established safety guidelines for 5G exposure in order to reduce thermal effects and safeguard the public's health from severe heat damage. However, research into the non-thermal effects of prolonged low-level exposure to 60 GHz radiation is still ongoing. To completely grasp the health effects of widespread 5G implementation, more study is essential, especially incorporating human studies and longitudinal data.

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