Supplementary material for the paper entitled: A source-based measurement database for occupational exposure assessment of electromagnetic fields in the INTEROCC study: A literature review approach

Authors: Javier Vila, Joseph D Bowman, Lesley Richardson, Laurel Kincl, Dave L Conover, Dave McLean, Simon Mann, Paolo Vecchia, Martie van Tongeren and Elisabeth Cardis, on behalf of the INTEROCC Study Group

Annex II. Confidence Evaluation for EMF occupational measurements to be used in the OEMD

Reviewer: **Date:**
Source and frequency band: **Title of report or article:**

Confidence ratings:
High Confidence = 3; **Medium Confidence**=2; **Low Confidence=** 1; **No information**= 0, *fractional ratings can be used for unusual situations*

Confidence Factor	Options (in order of decreasing confidence)	Confidence level rating	Factor weight	Weighted rating	COMMENTS
Sampling strategy	Representative sample	3	1	3	A representative sample was obtained
	Convenience sample	2	1	2	A convenience sample was used
	Compliance sampling (looking for values over exposure limits)	1	1	1	A sample to allow compliance with legal limits was used
	No information	0	1	0	Inadequate data in paper to make an evaluation
Type of dosimetry	*Personal*	3	1	3	Meter/Probe attached to operator
	Operator position – worker location	2	1	2	Meter/Probe located at worker location
	Spot – other locations	1	1	1	Meter/Probe located elsewhere near the source
	No information	0	1	0	Inadequate data in paper to make an evaluation
Anatomical location	*Head*	3	1	3	Measurements made at head level
	Full body	2	1	2	Measurements made for whole

					body exposure even if some head exposure values were used to calculate the averages
	Body part other than head	1	1	1	Measurements made at a body part other than head or whole body
	No information	0	1	0	Inadequate data in paper to make an evaluation
Number of values used to get exposure average	≥ *6 values*	3	1	3	Average obtained from 6 or more values
	2-5 values	2	1	2	Average obtained from 2-5 values
	Only 1 value	1	1	1	Average obtained from just one measurement
	No information	0	1	0	Inadequate data in paper to make an evaluation
Type of values used to get average exposure	*Values for each unit or average values*	3	1	3	Single measurements or averages were used to calculate average exposure values provided
	Ranges of values	2	1	2	Average obtained from ranges
	Max Values Averaged	1	1	1	Average obtained from maximum values
	Other	1	1	1	Average obtained from other types of values
	No information	0	1	0	Inadequate data in paper to make an evaluation
Duty factor or monitoring duration	*Duty factor measured / full-shift monitoring*	3	1	3	Values obtained considering measured source duty factor
	Duty factor estimate / partial-shift monitoring	2	1	2	Values obtained considering estimated source duty factor
	No duty factor / monitoring period unrepresentative	1	1	1	Duty factor was not considered

	No information	0	1	0	Inadequate data in paper to make an evaluation
Nature of exposure scenario	*Real-life*	3	1	3	Measurements made at real-life scenarios
	Highly questionable	2	1	2	Measurements made at questionable scenarios
	Virtually impossible	1	1	1	Measurements made at very unlikely scenarios
	No information	0	1	0	Inadequate data in paper to make an evaluation
Quality and reliability of measurements	*Judgement*	0 - 3	1	0 - 3	Judgment based on type/quality of instruments used, calibration updated etc.
Weighted average of the confidence level ratings for this reference		0 - 24	8	0 - 24	The final weighted average is obtained by dividing the weighted rating (0-24) by the total number of factors assessed (usually 8).
Paper too weak to be used in the exposure assessment?					Yes/No response.
Paper has measurements with distance?					Yes/No response.

Notes: 1) Factor weight was a feature added to allow the experts assign different weights to the factors assessed. However, this option was never used in INTEROCC and therefore factor weight is always equal to 1. Consequently, the weighted ratings are always equal to the confidence level ratings. 2) The question "Paper too weak to be used in the exposure assessment?" was used to identify papers to be considered for exclusion from OEMD (Annex V), together with the weighted average cut-off <1, as described in the Methods. 3) The question "Paper has measurements with distance?" was not used in the papers evaluation since papers without distances were finally also accepted.

Annex III. OEMD Data Dictionary

Fields	Meaning	Value label	Data type	Comments
ID	ID of the OEMD entry		text	This ID identifies each row in the OEMD
FreqBand	Default Frequency band		text	When more than one frequency is reported we have repeated the row to allow for a separate record for each frequency band
Source	Name/short description of the EMF source measured		text	
IradTable	Name of the IRAD table in which the field is found		text	It allows to link with the INTEROCC database, IRAD
IradField	Name of the specific IRAD field		text	It allows to link with the INTEROCC database, IRAD
IradValue	Code of the IRAD field to which these measurements apply		numeric	It allows to link with the INTEROCC database, IRAD
IradLabel	Label of the value from IRAD field		text	Name of the EMF source in the INTEROCC database, IRAD
Source Details	Detailed description of the EMF source measured		text	This detailed information coincides with the description provided in the document
Reference	The article/report from which the exposure information has been extracted		text	
N	Number of measurements	8888=see remarks 9999=not given	numeric	Optional value, not always available
FreqRange	Frequency range of either the instrument or the source		text	Original information extracted from the document as text entries

Fields	Meaning	Value label	Data type	Comments
FreqRangeLow	Lowest frequency value	999999=unknown	numeric	If only one value given it is entered in Low column When more than one value is reported we have repeated the row to allow for a separate record for each, with the appropriate frequency band
FreqRangeHigh	Highest frequency value	999999=unknown	numeric	
FreqRangeUnit	Unit of the frequency		text	Hz, kHz, MHz, GHz or Unkownn
Distance			text	Free text describing how measurement was made and at what distance from the source
DosimetryTypeLabel	How measurements were obtained	spot personal operator position review	text	Spot: Measurements were taken in the vicinity of the EMF source (cables, machinery, etc) Personal: Measurements were taken by a device attached to the operator´s body (normally the waist) Operator position: Measurements were the operator normally stands/works (e.g. head, chest etc) 4. Review: Measurement data came from a review paper, hence it is not possible to know the exact dosimetry used
DosimetryTypeCode	Codes for each type of dosimetry	1 = spot 2 = personal 3 = operator position 4 = review	numeric	

Fields	Meaning	Value label	Data type	Comments
LocationVerticalLbl	Where the measurement was taken in relation to the subject	source operator position head floor waist knees multiple chest	text	When dosimetry type is personal the default value is waist
LocationVerticalCode		1 = source 2 = operator position 3 = head 4 = floor 5 = waist 6 = knees 7 = multiple 8 = chest	numeric	For spot measurements the default is 4 = floor, if there is no information given
DistanceVerticalLower	Vertical distance from the location to the meter		numeric	For spot measurements the default is 100cms if there is no information given When dosimetry type is personal the default value = 0
DistanceVerticalUpper			numeric	
DistanceVerticalUnits		cms	text	
LocationHorizontalLbl	Where the measurement was taken in relation to the subject	source operator position	text	When dosimetry type is personal this should be blank
LocationHorizontalCode		1 = source 2 = operator position	numeric	
DistanceHorizontalLower	Horizontal distance from the location to the meter from the location to the meter		numeric	When the horizontal location is operator position the default = 0

Fields	Meaning	Value label	Data type	Comments
DistanceHorizontalUpper			numeric	
DistanceHorizontalUnits		cms	text	
Rater1EFields	Link to Confidence Evaluation ID for 1st rater concerning e-fields		numeric	These are repeated for different raters (up to 5 raters)
Rater1HBFields	Link to Confidence Evaluation ID for 1st rater concerning H or B-fields		numeric	
Rater1Any	Link to Confidence Evaluation ID for 1st rater concerning any fields		numeric	
Rater1Comments	Usually the name of the rater		text	
EFieldMin	Minimum value of E-field in volt per metre (V/m)		numeric	Electric field strength in volt per meter (V/m)
EFieldMax	Maximum value of E-field in volt per metre (V/m)		numeric	
EFieldRange	Range of values of E-field in volt per metre (V/m)		text	Free text field
EFieldMean	Mean value of E-field in volt per metre (V/m)		numeric	Normally Arithmetic Mean but also Time-Weighted Average (TWA) can be entered here
EFieldOtherStat	An additional statistic other than min, max or mean (e.g. GM, mode etc)		numeric	Normally Geometric Mean (GM) but also median, standard deviations, central tendency or other statistics provided can be entered here
EFieldStatUsedLbl	Specification of the other statistic used	geometric mean mode confidence limits peak values	text	

Fields	Meaning	Value label	Data type	Comments
		standard deviation central tendency		
EFieldStatUsedCode		1 = geometric mean 2 = mode 3 = confidence limits 4 = peak values 5 = standard deviation 6 = central tendency	numeric	
EFieldOutsideDynamicRange	Specification of the minimum in the dynamic range of the measurement instrument for E-field Original data as entered (including < or >)		text	When this is blank, the measurements fell within the dynamic range of the instrument
EFieldOutsideDynamicRange Min	Specification of the minimum in the dynamic range of the measurement instrument for E-field		numeric	When this is blank, the measurements fell within the dynamic range of the instrument
EFieldOutsideDynamicRange Max	Specification of the maximum in the dynamic range of the measurement instrument		numeric	When this is blank, the measurements fell within the dynamic range of the instrument
HFieldMin	Minimum value of H-field in ampere per metre (A/m)		numeric	Magnetic field strength in ampere per meter (A/m)
HFieldMax	Maximum value of H-field in ampere per metre (A/m)		numeric	If only one measurement available, it must be in entered in Max
HFieldRange	Range of values of H-field in ampere per metre (A/m)		text	Free text field
HFieldMean	Mean value of H-field in ampere per metre (A/m)		numeric	Normally Arithmetic Mean but also Time-Weighted Average (TWA) can

Fields	Meaning	Value label	Data type	Comments
				be entered here
HFieldOtherStat	An additional statistic other than min, max or mean (e.g. GM, mode etc)		numeric	Normally Geometric Mean (GM) but also median, standard deviations, central tendency or other statistics provided can be entered here
HFieldStatUsedLbl	Specification of the other statistic used	geometric mean mode confidence limits peak values standard deviation central tendency	text	
HFieldStatUsedCode		1 = geometric mean 2 = mode 3 = confidence limits 4 = peak values 5 = standard deviation 6 = central tendency	numeric	
HFieldOutsideDynamicRange	Specification of the minimum in the dynamic range of the measurement instrument for H-field Original data as entered (including < or >)		text	When this is blank, the measurements fell within the dynamic range of the instrument
HFieldOutsideDynamicRangeMin	Specification of the minimum in the dynamic range of the measurement instrument for the H-field		numeric	When this is blank, the measurements fell within the dynamic range of the instrument
HFieldOutsideDynamicRangeMax	Specification of the maximum in the dynamic range of the measurement instrument for the H-field		numeric	When this is blank, the measurements fell within the dynamic range of the instrument

Fields	Meaning	Value label	Data type	Comments
BFieldMin	Minimum value of B-field in microtesla (μT)		numeric	Magnetic flux density in microtesla (μT)
BFieldMax	Maximum value of B-field in microtesla (μT)		numeric	
BFieldRange	Range of values of B-field in microtesla (μT)		text	Free text field
BFieldMean	Mean value of B-field in microtesla (μT)		numeric	Normally Arithmetic Mean but also Time-Weighted Average (TWA) can be entered here
BFieldOtherStat	An additional statistic other than min, max or mean (e.g. GM, mode etc)		numeric	Normally Geometric Mean (GM) but also median, standard deviations, central tendency or other statistics provided can be entered here
BFieldStatUsedLbl	Specification of the other statistic used for B-fields	geometric mean mode confidence limits peak values standard deviation central tendency	text	
BFieldStatUsedCode		1 = geometric mean 2 = mode 3 = confidence limits 4 = peak values 5 = standard deviation 6 = central tendency	numeric	
BFieldOutsideDynamicRange	Specification of the minimum in the dynamic range of the measurement instrument for B-field Original data as entered (including < or >)		text	When this is blank, the measurements fell within the dynamic range of the instrument

Fields	Meaning	Value label	Data type	Comments
BFieldOutsideDynamicRange Min	Specification of the minimum in the dynamic range of the measurement instrument for the B-field		numeric	When this is blank, the measurements fell within the dynamic range of the instrument
BFieldOutsideDynamicRange Max	Specification of the maximum in the dynamic range of the measurement instrument for the B-field		numeric	When this is blank, the measurements fell within the dynamic range of the instrument
PowerDensityMin	Minimum value of Power Density		numeric	Power density (PD) in W/m^2
PowerDensityMax	Maximum value of Power Density		numeric	
PowerDensityRange	Range of values of Power Density		text	Free text field
PowerDensityMean	Mean value of Power Density		numeric	Normally Arithmetic Mean but also Time-Weighted Average (TWA) can be entered here
PowerDensityOtherStat	An additional statistic other than min, max or mean (e.g. GM, mode etc)		numeric	Normally Geometric Mean (GM) but also median, standard deviations, central tendency or other statistics provided can be entered here
PowerDensityOtherStatUsed Lbl	Specification of the other statistic used for Power Density	geometric mean mode confidence limits peak values standard deviation central tendency	text	
PowerDensityOtherStatUsed Code		1 = geometric mean 2 = mode 3 = confidence limits 4 = peak values	numeric	

Fields	Meaning	Value label	Data type	Comments
		5 = standard deviation 6 = central tendency		
PowerDensityOutsideDynamicRange	Specification of the minimum in the dynamic range of the measurement instrument for Power Density (PD) Original data as entered (including < or >)		text	When this is blank, the measurements fell within the dynamic range of the instrument
PowerDensityOutsideDynamicRangeMin	Specification of the minimum in the dynamic range of the measurement instrument for the Power Density (PD)		numeric	When this is blank, the measurements fell within the dynamic range of the instrument
PowerDensityOutsideDynamicRangeMax	Specification of the maximum in the dynamic range of the measurement instrument for the Power Density (PD)		numeric	When this is blank, the measurements fell within the dynamic range of the instrument
DutyCycleFactor	Proportion of working time that the source is in operation		numeric	Values should range from 0-1
ContactCurrentmA	Specific measure of personal exposure		text	
InducedCurrentsmA	Specific measure of personal exposure		text	
Remarks				

Annex IV. Terminology and physical relationships for electric and magnetic fields

OEMD uses the following terminology and physical relationships for compiling measurement data for the magnetic flux density (B), magnetic field strength (H), electric field strength (E) and power density (PD).

A. Magnetic fields. The B- and H-fields are different physical quantities with their own units that are both essential for quantifying magnetism in ferromagnetic materials. For health studies that mostly involve biological tissue and air, the B and H vectors are parallel, and their magnitudes are related by the conversion of their units:

$$B[\mu T] = \mu_0 \, H[A/m] \qquad \text{(V-1)}$$

where the permeability of the vacuum $\mu_0 = 4\pi \times 10^{-7}$ Henrys/meter. The constant μ_0 is used for air and biological tissues because their permeabilities deviate from the vacuum value by less than 10^{-8}, a negligible difference in health studies.[1] Note that μ_0=1.26 μT/(A/m) in the units generally used in health studies, so B[μT] and H[A/m] at any location are the same order of magnitude.

Since the B- and H-fields are physical equivalent for purposes of occupational and environmental health, each has been selected for magnetic field measurements at a different frequency band by consensus among researchers. In the radio-frequency (RF) band, the H-field is generally used, while the B-field is used for the extremely low frequency (ELF) and static magnetic field (SMF) bands.[2] OEMD follows these conventions in recording magnetic field data for the RF, ELF and SMF bands.

For the newly-defined Intermediate Frequency (IF) band, no consensus on magnetic fields has been achieved, so OEMD contains both B and H data. Since publications generally report only one type of magnetic field, equation V-1 was used to convert reported B data to H values for OEMD, and vice versa when H is reported.

B. Electric and magnetic fields in the near and far fields. In OEMD, the electric fields (E) and magnetic fields (H and/or B) are both recorded so they can be used as independent agents during epidemiologic analyses. This decision was based on both the physical properties of electromagnetic radiation and hypotheses for biophysical mechanisms by which EMF might cause cancer and other chronic diseases.

The electric and magnetic fields are uncorrelated in the "near field" within roughly a wavelength λ of their source,[3] so they must be treated as independent agents in risk analyses for workers in the near field. To be specific, the frequency bands used in OEMD (Table 1) have the following ranges for their wavelengths:

INTEROCC bands	ITU bands	Freq.	λ[m]
SMF	SMF	0 Hz	NA
ELF	ELF	3-3000 Hz	100 – 10^5 km
IF	VLF-LF	3-300 kHz	1-100 km
IF	MF-HF (< 10 MHz)	0.3-10 MHz	30-1,000 m
RF	HF (≥10 MHz)-VHF	10-300 MHz	1-30 m
RF	UHF-MW	>300 MHz	< 1m

where λ[m] = c / f[Hz] for the speed of light $c = 3 \times 10^8$ m/s. Since most work occurs within a few meters of a source, the near field therefore encompasses all exposures in the ELF and IF bands plus the lower frequency RF.

In the "far field", however, the electric and magnetic field magnitudes are perfectly correlated by the well-known relationship for electromagnetic radiation:[4]

$$E[V/m] = H[A/m] * 377 \text{ ohms} \qquad \text{(V-2)}$$

where 377 ohms = the impedance of free space. Even in the far-field part of the RF band where the two fields are correlated, they can still have different biological effects. The best documented example of a purely magnetic effect are the biological changes attributed to the coupling of RF magnetic fields with the electron spins in radical pairs.[5,6] However, other EMF biomechanisms such as thermal heating and electrostimulation of cell membranes can involve the E-field or the two fields combined. Since none of these mechanisms have been shown to cause cancer, the INTEROCC study protocol was developed on the empirical assumption that the initial epidemiologic analyses would model the electric and magnetic fields as independent exposures in all frequency bands.

OEMD also uses near field / far field relationships for manipulating RF data, based on the following rules:

Near-field / far-field boundary: For dipole antennas broadcasting at a single frequency, the far field begins at $\lambda/2\pi = 0.16\ \lambda$ but the boundary can be greater for other antenna geometries and broadband frequency spectra.[7] Since neither these antenna details nor the worker's location are known for all OEMD data, we adopted 1 m ➔ 300 MHz as a conservative far-field boundary for classifying RF data. In terms of the ITU frequency bands (table above), *data on HF-VHF fields are therefore assumed to be in the near field, while UHF-MW data are far field.*

Near Field: In the HF-VHF band, the H- and E-fields are assumed to have no mathematical relationship. For epidemiological analyses, missing H data for a source will be approximated by developing regression models for each statistic (i.e. mean, min, max) of H vs. E from similar sources in the OEMD.

Far Field: In the UHF-MW band, EMF exposure assessments are mostly in the far-field and report only E-field measurements. Therefore, the theoretical relationship (eq. V-2) is used to calculate H-field exposures for OEMD (or the inverse of eq. V-2 when H is reported).

C. <u>Power Density.</u> In the far-field, power density (PD) is often measured instead of the E- or H-fields, so these data are recorded in OEMD in units of W/m^2. With older studies that report PD data in the CGS units of mW/cm^2, the conversion factor $1\ mW/cm^2 = 10\ W/m^2$ is used.

Since the PD is not well-defined in the near field, the INTEROCC study decided not to use this quantity in epidemiologic analysis, but instead converts PD data to E and H, using the free-space relationships:

$$E\ V/m = \sqrt{PD\left[W/m^2\right] * 377\text{ ohms}}$$
$$H\ A/m = \sqrt{PD\left[W/m^2\right] / 377\text{ ohms}} \quad \text{(V-3)}$$

which come from substituting eq. V-2 into PD[W/m^2] = E[V/m] H[A/m], the basic relationship between these three magnitudes comprising electromagnetic radiation.[4]

D. Data checking. Data extracted into OEMD were checked for consistency with the theoretical relationships between B, H, and E in certain frequency bands:

i. For VLF-LF and MF-HF (IF) data, check B and H data - if they both exist – for compliance with eq. V-1. If one or the other is not reported, then calculate the missing field with eq. V-1.
ii. For UHF-MW data, check whether H and E obey the far-field relationship eq. V-2 when data for both fields are entered into OEMD.

References

1. Hitchcock RT, Patterson RM. (1995) *Magnetic permeability. In: Radio-frequency and ELF Electromagnetic Energies. A Handbook for Health Professionals.* New York, USA: Van Nostrand Reinhold. ISBN: 9780471284543.

2. Bowman JD, Kelsh MA, Kaune WT. (1998) *Units. In: Manual for Measuring Occupational Electric and Magnetic Field Exposures*. Cincinnati, Ohio, USA: DHHS, CDC, National Institute for Occupational Safety and Health (NIOSH). Available at http://www.cdc.gov/niosh/docs/98-154/pdfs/98-154.pdf (accessed 12 May 2015)

3. Hitchcock RT, Patterson RM. (1995) Near/far fields and plane waves. *In: Radio-frequency and ELF Electromagnetic Energies. A Handbook for Health Professionals.* New York, USA: Van Nostrand Reinhold. ISBN: 9780471284543.

4. Hitchcock RT, Patterson RM. (1995) Free-space impdedance. *In: Radio-frequency and ELF Electromagnetic Energies. A Handbook for Health Professionals.* New York, USA: Van Nostrand Reinhold. ISBN: 9780471284543.

5. Binhi VN. (2002) *Biological effects of microwaves and ion interference*. In: *Magnetobiology: Underlying Physical Problems.* San Diego, USA: Academic Press. ISBN: 0121000710.

6. Usselman RJ, Hill I, Singel DJ *et al*. (2014) Spin biochemistry modulates reactive oxygen species (ROS) production by radio frequency magnetic fields. *PLoS ONE* 9: e93065.

7. Balanis CA. (2005) Antenna Theory Analysis and Design. Chichester, UK: John Wiley & Sons, Inc. ISBN: 047166782X.

Table SI. Number of entries in the database by type of statistic, dosimetry and electric or magnetic field.

Statistic (dosimetry type) \ EM field	E-field [V/m]	H-field [A/m]	B-field [μT]	Power Density [W/m^2]	Total number of entries
Single measurement (spot/operator)	218	35	94	88	435
TWA[a] (personal)	--	--	7	--	7
Maximum (spot/operator)	367	198	290	75	930
Minimum (spot/operator)	159	88	179	46	472
AM[b] (spot/operator)	63	43	258	14	378
Maximum (personal)	43	15	117	--	175
Minimum (personal)	31	--	94	--	125
AM (personal)	45	14	171	--	230
Maximum (review)	86	54	--	1	141
Minimum (review)	42	19	--	--	61
AM (review)	1	--	--	8	9
GM[c] (all types)	19	18	59	--	96
ODR[d]Min (all types)	17	41	5	2	65
ODR Max (all types)	11	4	--	2	17
Total number of entries	1,102	529	1,274	236	3,141

The total number of entries in the database (n=3,141) surpasses the number of sets of measurements (n= 1,624), since each set of measurements may contain one of more statistics for each source and field, by frequency band and dosimetry type.

a) TWA: Time-Weighted Average
b) AM: Arithmetic Mean
c) GM: Geometric Mean
d) ODR: Outside Dynamic Range

Table SII. Number of measurements by occupational section and dosimetry type

Occupational section	Frequency band	Personal	Operator position	Spot	Review	Total number of entries
Heating Food & Medical-Dental	ELF, IF & RF	2	18	81	2	103
Industrial Heating	SMF, ELF, IF & RF	26	237	66	2	331
Diagnosis & Treatment	SMF, ELF, IF & RF	1	55	147	60	263
Transmitters	RF	--	7	52	5	64
Semiconductors	RF	30	57	28	--	115
Radars	RF	--	4	126	10	140
Telecommunication Antennas	RF	--	51	105	24	180
Electric Utilities	ELF	100	8	5	--	113
Electric Transport	ELF	1	13	12	--	26
Electrician & Electric Equipment CRM[a]	ELF	1	2	--	--	3
Electric Motors	ELF	29	91	166	--	286
Total number of entries	ALL	190	543	788	103	1,624[b]

a) CRM: Construction, repair and maintenance.

b) This figure represents the total number of sets of measurements in the database. Each set of measurements may contain one or more statistics.