CALCULATION OF INDUCED ELECTRIC FIELDS IN HUMAN MODELS EXPOSED TO ELF MAGNETIC AND ELECTRIC FIELDS

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Abstract: There has been increasing public concern about biological interactions and the potential health effects of low-frequency electric and magnetic fields (LF-EMFs). Recently, the ICNIRP have published new guidelines for LF-EMFs, which physical quantity of the basic restrictions has been changed into internal electric fields from current densities. The aim in this paper is to demonstrate induced electric fields in real human models of whole body exposed to electric or magnetic field at 60Hz, and is to compare those results with the basic restrictions. Calculations of the induced fields in the models were carried out using the SPFD method for magnetic field exposure and a hybrid two-stage approach with a finite difference method for electric field exposure. As a result, calculated internal electric fields in the human models for all scenarios are sufficiently lower than the basic restrictions.

1 INTRODUCTION

There has been increasing public concern about biological interactions and the potential health effects of low-frequency electric and magnetic fields (LF-EMFs). Human exposure to the LF-EMFs results in induction of the electric fields and the resultant current densities in a body. Some data under simplified model conditions such as an ellipsoidal model or a coarse human model including several organs have been reported [1]. Meanwhile, several human models, realistically human in nature, have been recently developed [2], and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) have published new guidelines for LF-EMFs [3], which the physical quantity of the basic restrictions has been changed into internal electric fields from current densities. The basic restrictions for general public exposure are 24mV/m for the central nervous system (CNS) tissue of the head and 400mV/m for other tissues of the head and body at 60Hz. The aim in this paper is to demonstrate induced electric fields in some real human models of the whole body which have been exposed to uniform electric or magnetic field at 60Hz, and to compare those results with the basic restrictions. In addition, the results due to different constitutions of the body are discussed.

2 METHODS AND HUMAN MODELS

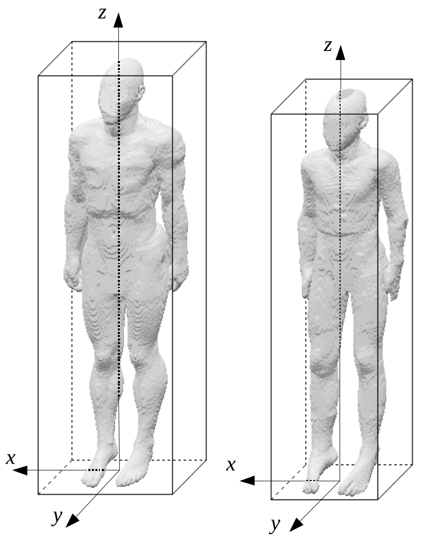
2.1 Calculating procedure

The Scalar Potential Finite Difference (SPFD) method is used to calculate electric fields induced in a human model exposed to LF magnetic fields in this paper. This method is also employed by some organizations, and a detailed description can be found elsewhere [4].

In order to calculate induced electric fields in the human model exposed to an external electric field for low-frequency, the finite difference method was used, considering computational domain including both a sufficient air space and a human model. Therefore, it requires a large volume of data. In this study, first, roughly-divided voxels for the computational domain were applied, and scalar potential values on the surface of a rectangular solid including the human model, as represented in Figure 1, were obtained. Then, electric fields inside the rectangular space which includes both regions inside and outside the human model were solved with finer voxels.

2.2 Numerical human models

Three numerical models of a realistic human body were used in this paper. One model was of an adult male of an average Japanese (Taro), 173cm in height and 65kg in weight, developed by NICT, Japan [5]. The other two models were adult and young European males, 174cm and 70kg for Duke, and 165cm and 50kg for Louis, respectively, developed by IT'IS Foundation [2]. Figure 1 shows the surface configuration of the two European models. Each voxel of these numerical models is identified with 58 - 80 distinct tissues/organs. The typical conductivity value of the tissue/organ at 50/60Hz is assigned to each tissue in advance. In addition, different voxel sizes are available for the two European models. Therefore, a different voxel size (5mm voxel for preliminary calculation and 2mm voxel for finer calculation) was applied for the computation of E-field exposures.



(a) Adult male (Duke) (b) Young male (Louis)

Figure 1: Numerical human bodies of the European models used in this study.

2.3 Numerical conditions

In the case of uniform B-field exposure, three directional exposures were considered: side-to-side, front-to-back, and head-to-feet against the human body. Each magnetic field strength was set to be 200μT, which is the reference levels of the new ICNIRP guidelines for general public exposure. The calculation was done for the three numerical human models which are constructed by 2mm voxels. Consequently, the total number of voxels required for the calculation were 8 million, 8.5 million, and 6 million for Taro, Duke, and Louis, respectively.

Meanwhile, in the case of uniform E-field exposure, the two models of the European body were used for the calculation because the coarse (5mm) and fine (2mm) voxel data were available for the identical body model. Just one direction of exposure (head-to-feet) was considered, but the calculations were carried for the two scenarios. For one calculation the model was isolated in a free space of 10m x 10m x 31m. For the other calculation the model was standing on the ground, above which there is a space of 10m x 10m x 17m. For both calculations, it was confirmed that E-field is uniform in any rectangular space without the human model.

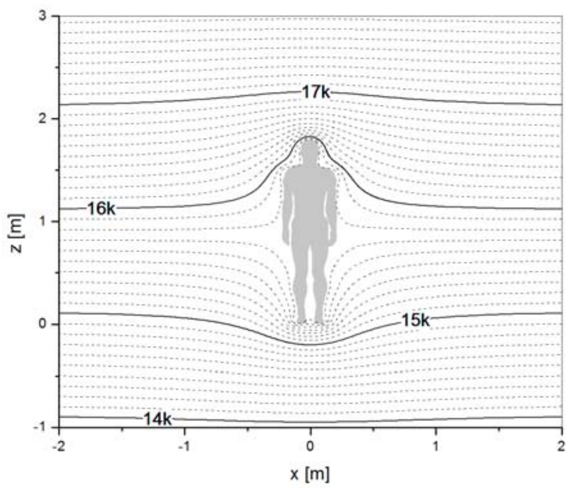
Finally, the basic restrictions of the new ICNIRP guidelines should be compared with average electric field induced in a small contiguous tissue volume of 2 x 2 x 2 mm^3. Therefore, the voxel size of the human models used was optimal, and no averaging algorithm was carried out in this study. But, for a specific tissue, the 99th percentile value of the electric field is the relevant value to be compared with the basic restrictions.

3 RESULTS

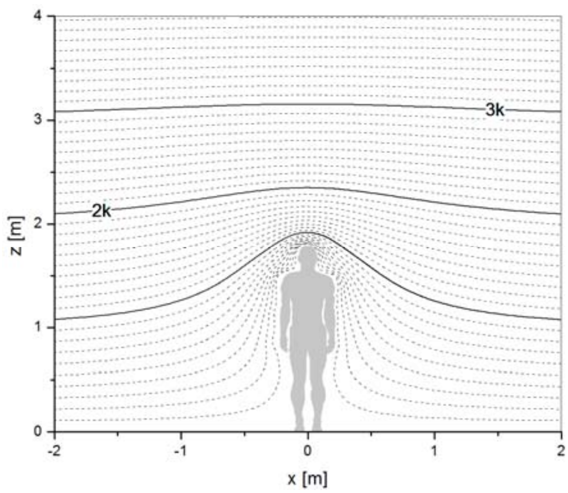
3.1 Induced fields by E-field

Figure 2 show detailed equipotential distributions around the adult human model in free space and grounded when uniform electric field of 1kV/m is exposed vertically to the human model. It is found from the Figure that the equipotential line in the vicinity of the human is perturbed and electric fields are perpendicular to every surface of the human for both scenarios.

Figure 3 shows the total currents flowing through the body as a function of the height for both the isolated and grounded models exposed to an electric field of 1kV/m at 60Hz. The currents rise steeply at the shoulders for both scenarios,



(a) isolated (free space)



(b) grounded

Figure 2: Equipotential line distribution around the human model (Duke) which is inside ELF uniform E-field of 1kV/m.

especially, for the grounded because the current injecting into the arm is flowing into the torso. Then, they decline gradually for the isolated and increase more for the grounded. In the case of the grounded model the total current flowing to the ground through feet is 18μA, and this value is good agreement with values reported by others [6].

Figure 4 shows the distribution of induced electric field which maximum value is projected on the coronal plane. It is found from the Figure that the induced fields for both scenarios are higher at a part of the head, lower abdomen, knees, and ankles, and it is found from Figures 3 and 4 that the induced field for the grounded are higher than that for the isolated, as expected. The values for the grounded are 2 times larger or more compared to those for the isolated. The 99 percentile values of the induced fields for the typical tissues are indicated in Table 1 when the model is exposed to electric field of 4.2kV/m which is the reference level of the new ICNIRP guidelines for general public.

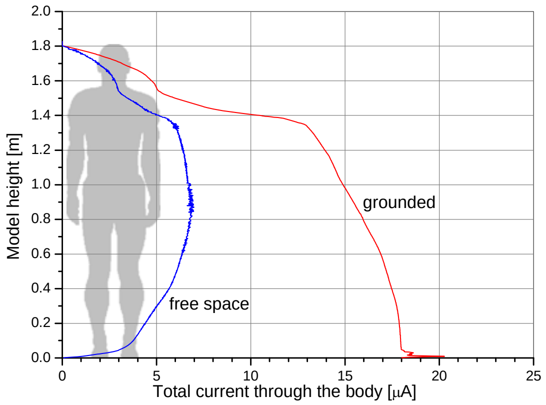
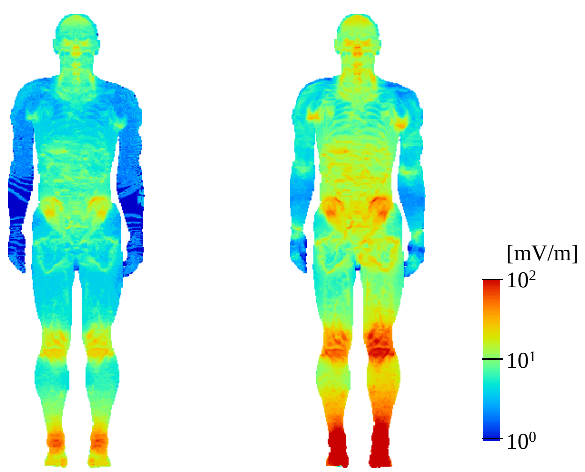


Figure 3: Total currents through the human model (Duke) being inside ELF uniform E-field of 1kV/m.



(a) isolated (b) grounded

Figure 4: Electric field distribution (maximum value is projected) on the coronal plane of the human model (Duke) exposed to 60 Hz uniform E-field of 4.2 kV/m.

Table 1: Induced electric fields (E_{99}) [mV/m] for each tissue inside the isolated (iso) and grounded (grd) humans exposed to 60Hz vertical electric field of 4.2 kV/m.

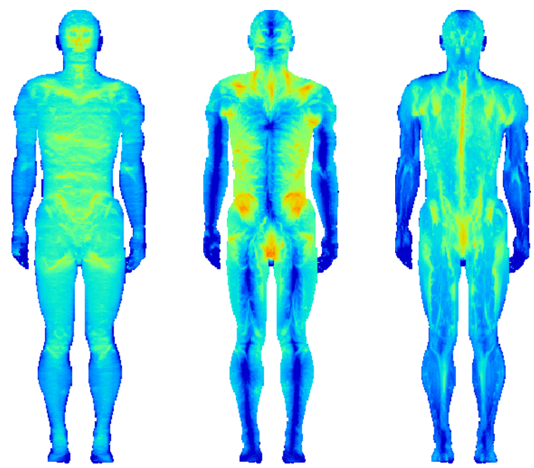
		tissue				
		Grey Matter	White Matter	Spinal Cord	Heart	Muscle
Duke	iso	6.03	4.81	8.72	5.65	10.55
	grd	9.78	7.92	14.92	11.99	50.27
Louis	iso	4.46	4.46	9.45	5.75	11.36
	grd	7.17	7.01	16.28	12.63	88.45

3.2 Induced fields by B-field

Figure 5 shows the distribution of induced electric field in which the maximum value is projected on the coronal plane of the model exposed to magnetic fields of 200μT (60Hz) which is the reference levels of the new ICNIRP guidelines for general public exposure. The direction of the current induced (eddy current) inside the body varies according to the direction of magnetic field exposure. Therefore, the electric field distributions inside the body differ completely. The larger electric fields due to *By* (front to back direction) can be observed especially at the torso of the body because the cross-sectional area perpendicular to the direction is larger. In the case of *Bx* exposure, the fields in the head become larger. The 99 percentile values of the induced fields for the typical tissues are indicated in Table 2 when the models are exposed to magnetic field of 200μT.

3.3 Comparison and discussions

From Tables 1 and 2, the induced electric fields for the grounded humans exposed to E-field are slightly higher than those of any other exposure. There was little difference among the model constitutions. As a result, it was found that the



(a) *Bx* exposure (b) *By* exposure (c) *Bz* exposure

Figure 5: Electric field distribution (maximum value is projected) on the coronal plane of the human model (Duke) exposed to ELF uniform B-field of 200μT. The colour scale is the same as Figure 4.

Table 2: Induced electric fields (E_{99}) [mV/m] for the typical tissues inside humans exposed to each directional 60Hz magnetic field of 200μT.

		tissue				
		Grey Matter	White Matter	Spinal Cord	Heart	Muscle
Duke	Bx	6.99	5.68	6.85	9.30	6.45
	By	5.62	4.62	5.64	6.50	10.58
	Bz	4.51	3.89	8.22	7.51	5.63
Louis	Bx	5.04	4.47	3.34	7.49	5.24
	By	4.93	4.58	1.56	6.63	9.30
	Bz	3.94	3.39	0.71	6.33	4.41
Taro	Bx	6.02	5.68	7.41	7.79	6.41
	By	5.56	4.76	6.79	8.32	9.89
	Bz	4.76	4.21	4.60	6.78	5.36

induced electric fields in the brain (grey matter and white matter) and other tissues for both exposures are lower than the basic restrictions of the new ICNIRP guidelines.

Figure 6 shows the average electric field on horizontal cross-section as a function of the model height for all five scenarios. The induced electric fields at the legs for the E-field exposure become much larger because the areas of knees and ankles are very small compared to other areas. It is clear that the vertical E-field exposure of a grounded human induces the higher electric fields, and they may extend to more than 100mV/m for torso. However, these values are also smaller than the basic restrictions for other tissues of the head and body.

4 CONCLUSION

In this paper, induced electric fields inside some

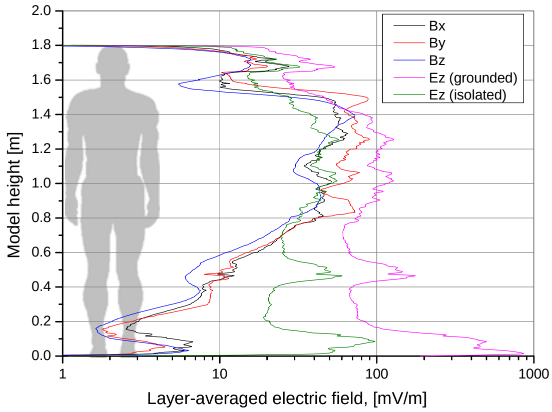


Figure 6: average induced electric fields on a cross-section of the human model (Duke) as a function of the model height in the case of both E-field (4.2 kV/m) and B-filed (200 μT) exposures of reference levels at 60Hz.

realistic models of the whole body exposed to uniform electric and magnetic fields at 60Hz, were compared with the basic restrictions of the new ICNIRP guidelines. Calculated internal electric fields in the CNS tissues and other tissues of all numerical human models used, against both exposures for the reference levels, are sufficiently lower compared to the basic restrictions.

Finally, the computational procedures can be applied in a practical way for such a worker standing on a power transmission tower or in a substation [7] and a person near an electric appliance.

5 ACKNOWLEDGMENTS

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