# 6-4

## SPECIFIC ABSORPTION RATE DISTRIBUTION IN A MODEL OF MAN AT VARIOUS POLARIZATIONS

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ABSTRACT

A computer-based scanning system and implantable electric field probes were used to obtain maps of the specific absorption rate (SAR) in various cross-sections of a full-scale model of the human body. The model was exposed to a plane-wave at 350 MHz at E and k polarizations with respect to the body. Enhanced absorption in the neck and the limbs, as previously found by the thermographic method, was observed. Significant differences between the SAR distribution and the SAR values calculated using the block model and those found in this work were observed.

### Introduction

The average specific absorption rate (SAR) has been used in quantifying interactions of electromagnetic fields with biological systems at radio and microwave frequencies. The importance of the distribution of the SAR within the exposed system is well recognized as an essential factor in quantifying resulting biological responses. In recent years numerous theoretical methods have been developed for dosimetry, as reviewed elsewhere (1). The analysis of the so called block model of man appears to be most promising in providing the SAR distribution (2-5). In view of importance of the SAR distribution as well as the values of the local SAR, it is essential that the theoretical data is quantitatively verified experimentally. There are two viable techniques for measuring SAR distributions. A thermographic method has been developed and successfully applied to scaled down models (6,7). The main limitations of this technique are: a limited spatial resolution due to the size of the models and a difficulty in incorporating the anatomical structure into such models.

An implantable electric field probe offers an alternative for measuring the SAR distribution. This technique has several advantages. In addition to being particularly suitable for measurements in full-scale models, the measurements are not dependent on the thermal properties of the model material. Not only the SAR, but also the direction of the electric field can be determined. Measurements can be performed using very low exposure fields, which do not cause any increase in the model temperature. Furthermore, the data can be conveniently obtained for a very large number of locations when an automatic probe-positioning system is used.

In this paper we present the results of the SAR distribution measurements in a full-scale model of man exposed to a plane-wave at 350 MHz. The data was obtained using a calibrated implantable electric field probe and a computer-controlled scanning system. The exposure frequency of 350 MHz was selected because of the reported head resonance at this frequency (5) and the availability of the SAR data for the block model of man (8).

### Experimental Arrangement

The experimental system, except for the computer, the generator and the monitoring equipment, was placed in an anechoic chamber. An exposure field was produced by a resonant dipole above the ground plane. The dipole was located below the model for the E polarization (i.e. the electric field vector parallel to the long axis of the body), or at the side of the model for the k polarization (i.e. the wave propagation from head to toe, the propagation vector parallel to the long axis of the body).

The scanning system composed of a mechanical structure for supporting and positioning of the probe and a computer-based system for control of the experiment, data acquisition, storage, display and recording are described elsewhere (9).

The full-scale styrofoam mold had the dimensions of a standard man. This mold was filled with a mixture of water, sugar and salt in such proportions that it had the following electrical properties: $\varepsilon' = 38$ and $\sigma = 0.95$ S/m. These properties correspond to the tissue "average" properties at 350 MHz (4,5).

Implantable triaxial electric field probes, model EIT 979 and Holaday IME-01 were used to measure the electric field intensity. These probes were previously fully characterized in terms of the sensitivity in the tissue phantom material, noise and modulation characteristics (10).

### Results and Discussion

The specific absorption rates (SARs) in several locations within the body in three cross-sections separated by 5 cm are shown in Figure 1

(a) and (b) for the E and k polarizations, respectively. Each data point is an average of at least five separate measurements. In all experiments the SARs were normalized to 1 $mW/cm^2$ of an incident power density at the plane corresponding to the body surface or the point closest to the radiation source.

Our data can be compared with the experimental results obtained by the thermographic technique (7). For the E polarizatrion maxima of the SAR were found by us in the neck and the thigh regions, quite similar to the thermographic data at 450 MHz (7). Even quantitatively, the agreement is close in view of the frequency difference, e.g., in the neck we found SAR = 86 mW/kg, vs SAR = 120 mW/kg reported at 450 MHz.

Our experimental data were also compared with the theoretical values obtained for the block model of man (4,5,8). Significant differences between calculated values of the SAR and our results were observed. The comparison is confunded by the differences in the shape of the models and locations of the comparison sites (while our method provided the SAR values within a relatively small volume of about 1 $cm^3$, the cells in the block model are much larger, > 10 $cm^3$). However, the observed differences are of an order of magnitude or more, and are likely to be due to other factors. Particularly large differences occur in the SAR distribution both in the head and the torso for the k polarization. Our experimental data show a nearly exponential decay of the SAR with distance from the surface (see Figure 1(b), with extremely low SAR in the legs, while the theoretical calculations show appreciable SAR values in the legs (8).

A rapid decrease of the SAR values within the torso as a function of the distance away from the radiation source for the E polarization is illustrated in Figure 2. The deposition of the energy at the body surface within the torso was also observed thermographically at 450 MHz (7). For the k polarization the SAR distribution is qualitatively very similar to that of an elipsoidal cylinder which is not surprising in view of the similarities in shape.

The SAR distributions in the head are shown in Figure 3. Corresponding SAR distributions in a 16-cm diameter sphere filled with the same phantom material are also shown for comparison. It can be noted that the shape of the curves is very similar, however, the quantitative results are slightly different. The SAR distribution in the head appears to be different than that for the block model of man (8) as no significant resonances were found at 350 MHz.

## Conclusions

Measurements of the specific absorption rate (SAR) distribution in a full-scale model of man filled with a phantom material having average tissue permittivity have been performed at 350 MHz for a far-field exposure and two polarizations. The use of a computer-controlled mechanical scanning system and implantable isotropic probes provided good spatial resolution, excellent reproductibility of results of ± 0.5dB, and a good absolute uncertainty of ± 1 dB. The measurements are fully automated and after proper calibrations and preparation, a large number of data points can be conveniently obtained without operator's assistance.

At 350 MHz a generally non-resonant behaviour of the human body, with maximum energy absorption at the surface on which the radiation is incident, was confirmed. This conclusion does not however apply to the head, neck and the limbs, where more complex distributions of the SAR were observed.

Our experimental data is in a relatively good agreement with the reported experimental results at 450 MHz obtained by the thermographic technique, (7), however, only a few features of the distribution could be compared.

The results of our experiments differ significantly from the values of the local SAR calculated for the block model of man (4,5,8). Particularly large differences occur in the head and torso for the k polarization. The distributions of the SAR in the head were found similar to that for a lossy sphere without any significant resonances at 350 MHz.

Our experimental results provide quantitative proof of serious limitations of the theoretical analysis of simplified models of man in terms of the distribution of energy. Our results also clerarly indicate the significance of obtaining the SAR distribution in a reliable manner under realistic conditions.

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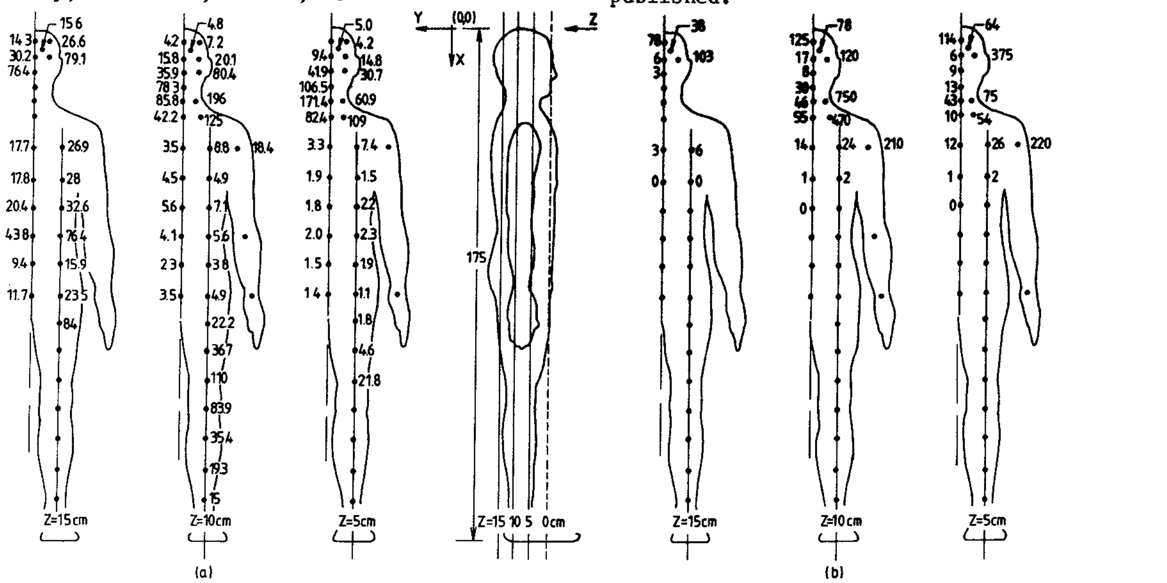


Figure 1. The specific absorption rate (SAR) in mW/kg for a plane-wave irradiation at 350 MHz and at a power density 1 mW/cm$^2$; on the surface of the model.

(a) the electric field vector parallel to the body long axis, E ll L, the propagation vector, k, from back to front.

(b) the propagation vector parallel to the long axis of the body K ll L, the electric field vector shoulder-to-shoulder, propagation head to toe.

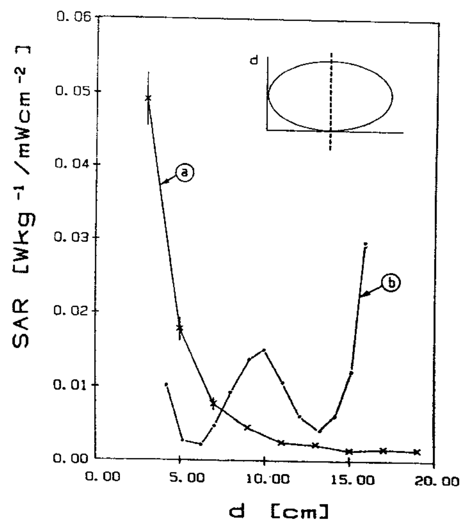


Figure 2. The specific absorption rate (SAR) distribution in the upper torso, for a plane-wave irradiation at a frequency of 350 MHz and a power density of 1 mW/cm$^2$.

(a) chest area - 48 cm from the top of the head. E || L, k from back to front, scanning along the k.

(b) chest area - 38.5 cm from the top of the head. k || L, the electric field should-to-shoulder, propagation from head to toe, scanning perpendicular to k and E.

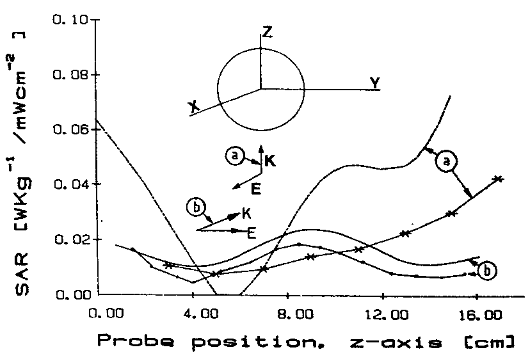


Figure 3. The specific absorption rate distribution in the head for a plane-wave irradiation at a frequency of 350 MHz and a power density of 1 mW/cm$^2$. Dashed lines are for a 16-cm lossy sphere - analytical results.