§12. Quantification and Safety Evaluation of Human Exposure to Stochastically Varying EM Fields

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Since the high frequency (HF) and microwave electromagnetic (EM) field leakages in the fusion experimental facilities are generated intermittently and have stochastically time-varying amplitudes, an approach to derive a statistically averaged specific absorption rate (SAR in unit of W/kg) is newly presented and used to evaluate the workers' safety. The approach is based on the measurements of the cumulative amplitude probability distributions (APD) of leaked electric fields. The APD is defined as

$$APD(E) = \int_E^\infty p(E)dE = \frac{1}{T_E}\sum_n^N \tau_n \quad (1)$$

where $p(E)$ is the probability density function of the electric field intensity, τ_n is the period of the n-th measurement time in which the electric field level exceeds E, and T_E is the total measurement time. Fig. 1 is a measured example for the APD of electric fields at 38.5 MHz leaked from a heating device in the ion cyclotron range of frequencies (ICRF). To translate the stochastically varying EM fields into SAR for the human safety evaluation, we derived the ensemble average of the SAR as

$$< SAR > = \int_0^\infty SAR(E^2)p(E)dE$$

$$= \int_0^\infty SAR(E^2)\left\{-\frac{\partial}{\partial E}APD(E)\right\}dE \quad (2)$$

which means that the ensemble-averaged SAR can be derived from the measured APD of electric fields. In the international safety guidelines, however, the safety limits are being generally defined as the SAR as averaged over 6-minutes. If the SAR belongs to an ergodic process, i.e., its time-average should be equal to its ensemble-average, we can derive the SAR from the APD measurement in lieu of the field measurement during a 6-minute period.

In order to examine whether the leaked field is ergodic, we compared the SAR derived from the APD measurement for a 20-second period with the SAR averaged over a 6-munite period. In the SAR calculation, we employed the finite-difference time-domain (FDTD) method together with an anatomically based human body model under the assumption of plane–wave exposure. The human body model is known as the "Visible Man" which consists of more than 40 types of tissue and has a resolution of 1 mm. Fig. 2 shows a visualization of the human body model and the SAR distributions at 38.5 MHz and 2.44 GHz for a plane-wave exposure with an electric field intensity of 61.4 V/m or a power density of 10 W/m^2. The former frequency (38.5 MHz) is for the ICRF heating device, and the latter frequency (2.44 GHz) is for a linear high-density plasma generator (HYPER-I). The high SARs were in the ankle region at 38.5 MHz but shifted to the head at 2.44 GHz. Table I shows the ensemble-averaged SAR derived from the APD measurement, and Table II shows the time-averaged SAR during 6 minutes. Comparing Table I with Table II, we found that the statistically averaged SARs were in fair agreement with the time-averaged SARs. The differences between them were within ± 20%. This finding demonstrates the usefulness of the APD measurement, which allows us to derive the time-averaged SAR without the necessity of measuring the electric field during the whole 6-minute period.

As for the SAR levels in the fusion experimental facilities, they were low enough compared to the safety guidelines.

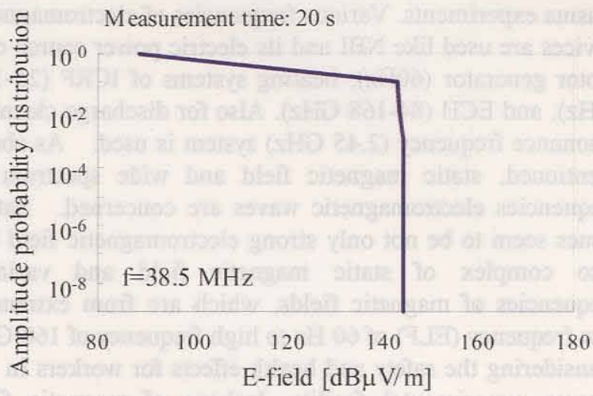

Fig. Measured APD of leaked electric fields from an ICRF heating device

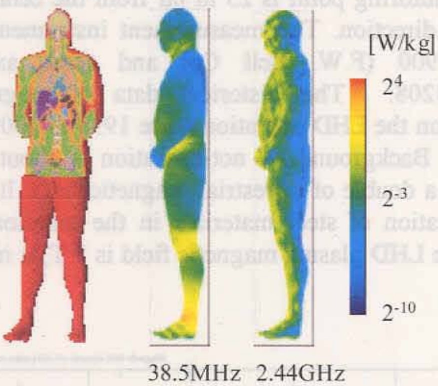

Fig. 2 SAR distributions for a plane-wave exposure under 10W/cm^2

Table I Ensemble-averaged SAR in major organs

	Whole Body	Brain	Eyes	Heart
ICRF (38.5 MHz)	3.502	0.928	0.958	2.305
HYPER-I (2.44 GHz)	0.034	0.011	0.442	0.008

Unit: mW/kg

Table I Time-averaged SAR in major organs

	Whole Body	Brain	Eyes	Heart
ICRF (38.5 MHz)	3.103	0.822	0.849	2.042
HYPER-I (2.44 GHz)	0.040	0.013	0.520	0.009

Unit: mW/kg