Full-wave dosimetry of adults and children from 450 MHz to 26 GHz

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2 Full-wave reference | **3** Indoor hybrid method | **4** Outdoor hybrid method | **5** Closed-form dosimetry | **6** Measurements and cities

Children absorb 1.5 to 1.9 times as much power per kilogram as adults below 6 GHz. At the reference level, whole-body SAR in the six-year-old is 93% of the limit averaged over 12 plane waves, and 145% for the worst of them.

1 Question

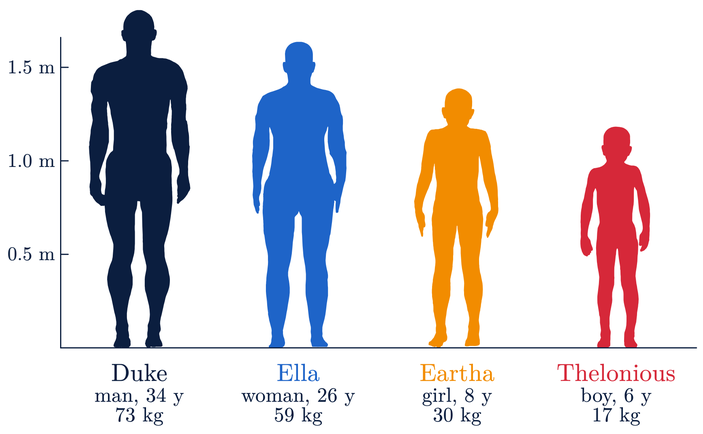
Exposure guidelines limit the power absorbed inside the body. These basic restrictions cannot be measured in a person, so the guidelines also specify reference levels for the incident field outside the body. Below the reference level, absorbed power should be below the basic restriction.

We check this relation for adults and children at 15 frequencies between 450 MHz and 26 GHz, for plane waves from six directions and for a beam focused on the user.

Basic restriction [2]	**Limit**	**Applies**
Whole-body SAR	0.08 W/kg	all frequencies
Peak SAR over 10 g	2 W/kg	head, torso, to 6 GHz
Absorbed power density	20 W/m^2	4 cm^2, above 6 GHz
Reference level [2]	10 W/m^2	above 2 GHz

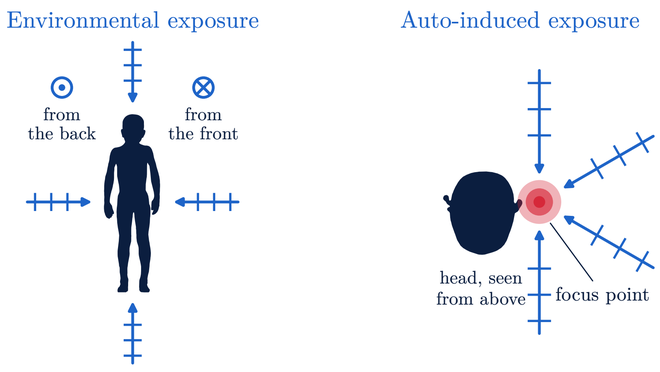
ICNIRP 2020 values for the general public. SAR: specific absorption rate. Below 2 GHz the reference level decreases to 2.25 W/m^2 at 450 MHz.

2 Method



Four body models of the Virtual Population [3], each with more than 300 tissues and organs.

We solve Maxwell's equations on a grid with the finite-difference time-domain (FDTD) method. The cell size decreases from 2.5 mm at 450 MHz to 0.3 mm at 26 GHz, and the cost increases with the fourth power of the frequency.



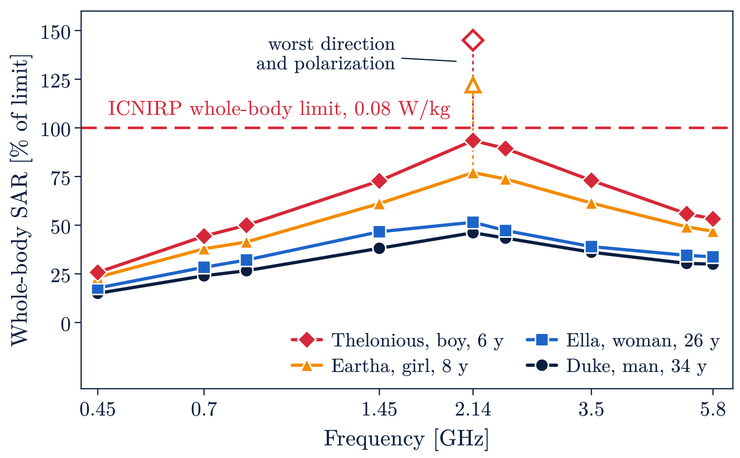
Exposure types. Left: 12 plane waves, six directions with two polarizations each. Right: four plane waves that add in phase at a focus point near the skin.

For the focused beam, wave i of $N = 4$ has the weight

$$w_i = \frac{1}{\sqrt{N}} e^{-j \arg E_{z,i}(\mathbf{r}_0)}, \qquad \mathbf{E}(\mathbf{r}) = \sum_{i=1}^{N} w_i \, \mathbf{E}_i(\mathbf{r}),$$

with $E_{z,i}$ the vertical electric field of wave i at the focus point $\mathbf{r}_0$, and $\mathbf{E}_i$ the simulated field of wave i in the whole body.

3 Absorption per kilogram



Whole-body SAR for an incident field at the ICNIRP reference level [2], averaged over 12 plane waves. Open markers: worst single plane wave at 2.14 GHz.

The whole-body specific absorption rate is

$$\mathrm{SAR}_{\mathrm{wb}} = \frac{\mathrm{ACS} \cdot S}{m},$$

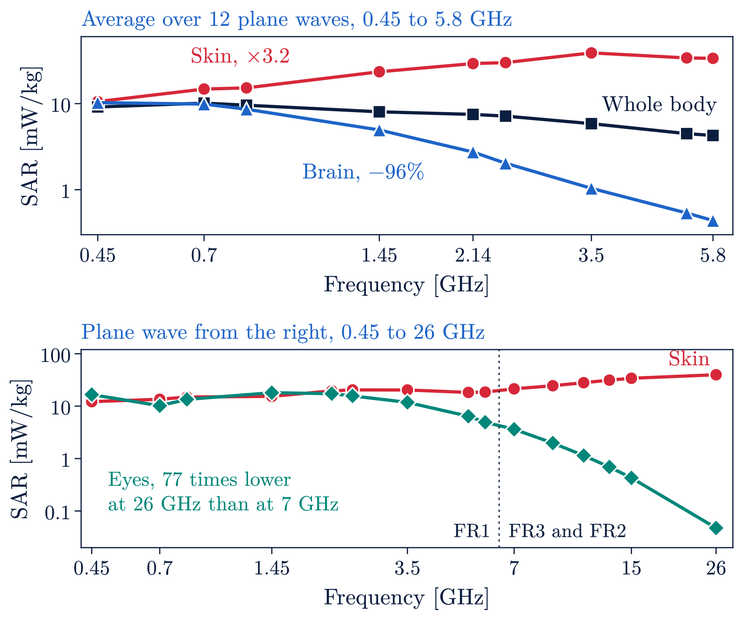
with ACS the absorption cross section [m^2], S the incident power density [W/m^2], and m the body mass [kg].

A child has a smaller cross section, but its mass is smaller still. The children's $\mathrm{SAR}_{\mathrm{wb}}$ is therefore 1.5 to 1.9 times the adult value below 6 GHz. The adult average is below 52% of the limit.

550
simulations, 15 frequencies, 4 body models

1.84×10^9
grid cells for one simulation at 26 GHz

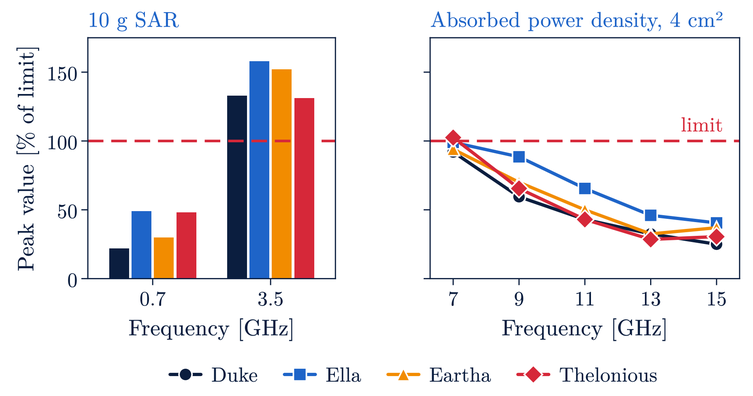
4 Absorption per tissue



SAR per tissue in the six-year-old model for an incident power density of 1 W/m^2.

The 90% power absorption depth decreases from 60 mm in muscle at 450 MHz to 1.1 mm in skin at 26 GHz. Therefore, skin SAR increases and brain SAR decreases with frequency. At 26 GHz the closed eyelid absorbs the field before it reaches the eye.

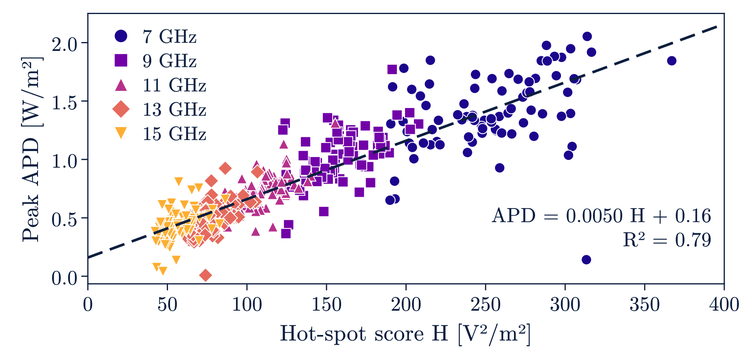
5 Exposure to a focused beam



Highest evaluated focus point per body model, for four waves whose power densities sum to the reference level. Left: peak SAR over 10 g. Right: APD over 4 cm^2. At 0.7 GHz, Duke and Eartha peak in the leg (4 W/kg limit).

The reference levels are set for a uniform plane wave. A focused beam with the same incident power density concentrates the field in a hot-spot. At 3.5 GHz the peak SAR over 10 g is 131 to 158% of the limit for all four models. At 7 GHz the APD is 92 to 103%, near the limit within the ±12% modelling uncertainty. At 15 GHz the hot-spot is smaller than the averaging area, and the APD is 25 to 40% of the limit.

6 Search for the worst focus point



Score against APD for 400 focus points at an incident power density of 1 W/m^2.

A full evaluation at every focus point costs too much. Therefore, we rank 10 000 candidate points per case with a score H, the mean of $|\mathbf{E}|^2$ over the skin in a cube of 50 mm around the point. Only the best 20 are fully evaluated, at 1/500 of the cost.

7 Conclusions

- At the reference level, a child can exceed the whole-body limit: 145% for the worst plane wave at 2.14 GHz.
- A focused beam at the reference level exceeds the 10 g SAR limit at 3.5 GHz. At 7 GHz the APD is at the limit within the ±12% modelling uncertainty.
- Measured exposure in daily life is three to four orders of magnitude below the reference level.
- Above 6 GHz the skin absorbs the field. Chapter 5 uses this property to replace the simulation with a formula.
- All results and the simulation framework are openly available [1].

References

[1] R. Wydaeghe *et al.*, "Environmental and auto-induced RF-EMF adult and children far-field exposure simulations between 450 MHz and 26 GHz," *Phys. Med. Biol.*, vol. 71, no. 17, art. no. 175006, 2026, doi: 10.1088/1361-6560/ae97ac. [2] ICNIRP, "Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz)," *Health Phys.*, vol. 118, no. 5, 2020. [3] M.-C. Gosselin *et al.*, "Development of a new generation of high-resolution anatomical models for medical device evaluation: the Virtual Population 3.0," *Phys. Med. Biol.*, vol. 59, no. 18, 2014. Data: doi: 10.7910/DVN/EEEE0X.

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