

Eye Dosimetry for Microwave and millimeter-wave Exposures -Review and Future Research-

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Basis of Current Guidelines and Recent Related Results @MW

- The eye is said to be one of the heat sensitive tissues due to lack of blood perfusion (cornea, lens, vitreous) and not covered by the skin.
- Temperature elevation may result in cataract formation ($\sim 41^{\circ}\text{C}$) [A].
- Local SAR of $\sim 140 \text{ W/kg}$ (power density of $1,500 \text{ W/m}^2$, 100 min) lead to eye temperature of 43°C [B].
- Eye averaged SAR in [B] was estimated as $\sim 60 \text{ W/kg}$ (weight of eye is 3 g) from computational model developed in Hirata et al [C].
- The organ-averaged SAR for the eye should not exceed 0.4 W/kg in the controlled environment. (note in CANADA)

$$SAR = \frac{\sigma E^2}{\rho}$$

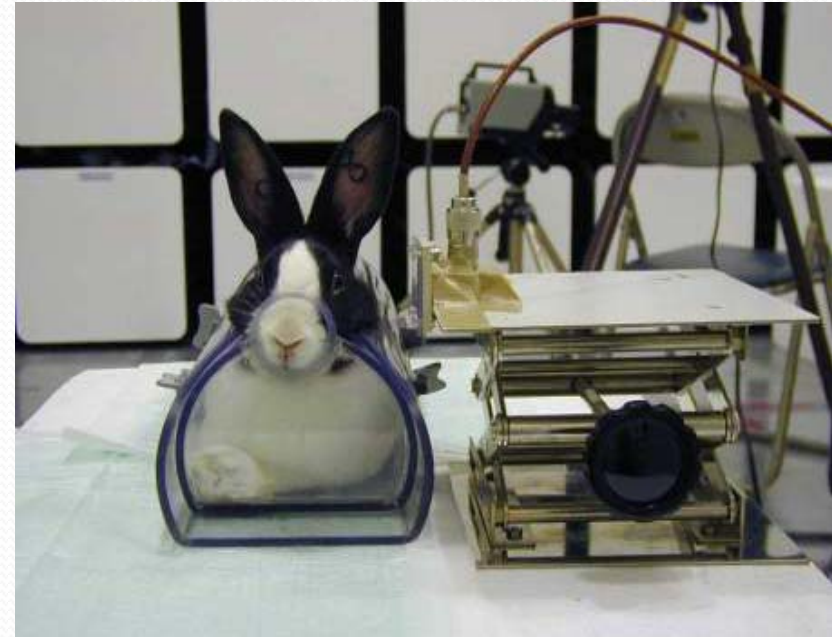
[A] J. Elder, *Bioelectromagnet.* 2003

[B] A. W. Guy et al, *IEEE MTT*, 1975

[C] A. Hirata et al, *Health Phys.*, 2008

Microwave Exposure on Rabbit Eye

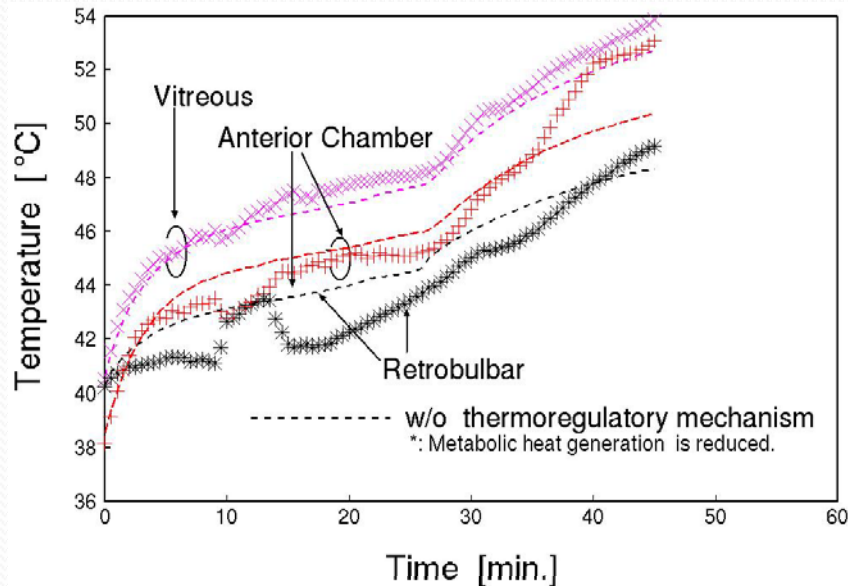
- Systemic anesthesia was administered in Guy et al. [A]
- Local anesthesia to the eye only was applied in Kojima et al [B].
- Eye temperature **with** systemic anesthesia was larger than that **without** systemic anesthesia.



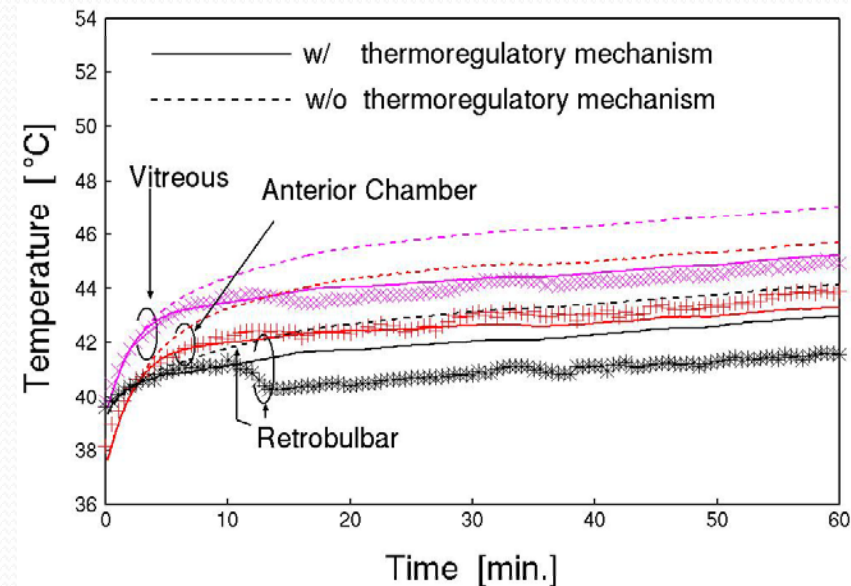
[A] A. W. Guy et al , *IEEE MTT*, 1975

[B] M. Kojima et al, *Bioelectromagnet.*, 2004

Time Evolution of Temperature in Rabbit Eye



With Systemic Anesthesia



Without Systemic Anesthesia

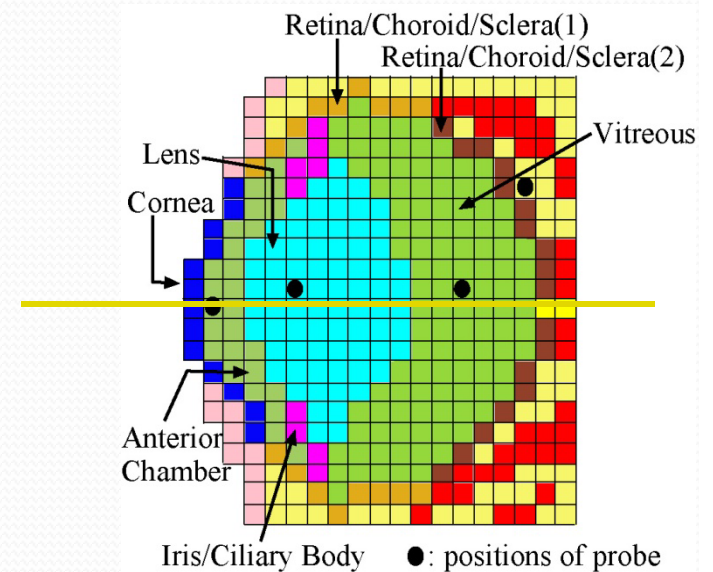
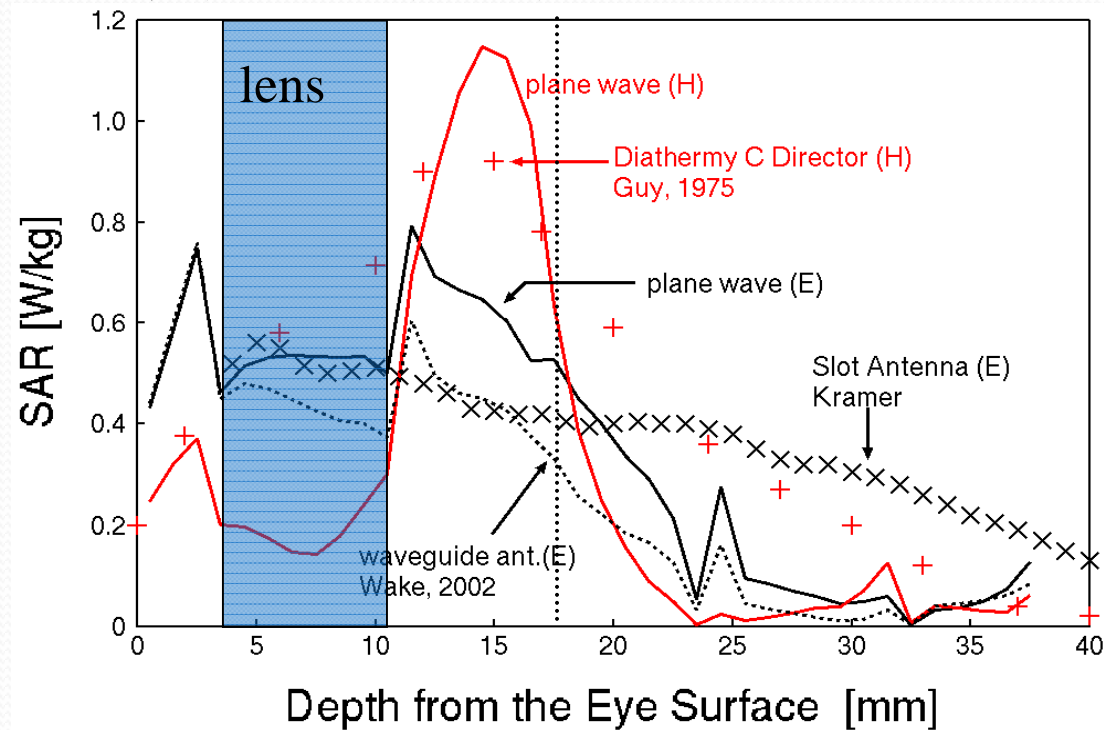
From (a), the temperature increases steeply after the death of the rabbit (at 26 min.). Thus, the blood flow and temperature increase could be close related to each other.

•From (b), the calculation results with the effect of thermoregulatory mechanism taken into account are in good agreement with measured data without anesthesia. The calculation results without thermoregulatory mechanism are overestimated as compared with measurements.

SAR Distribution for Different Sources

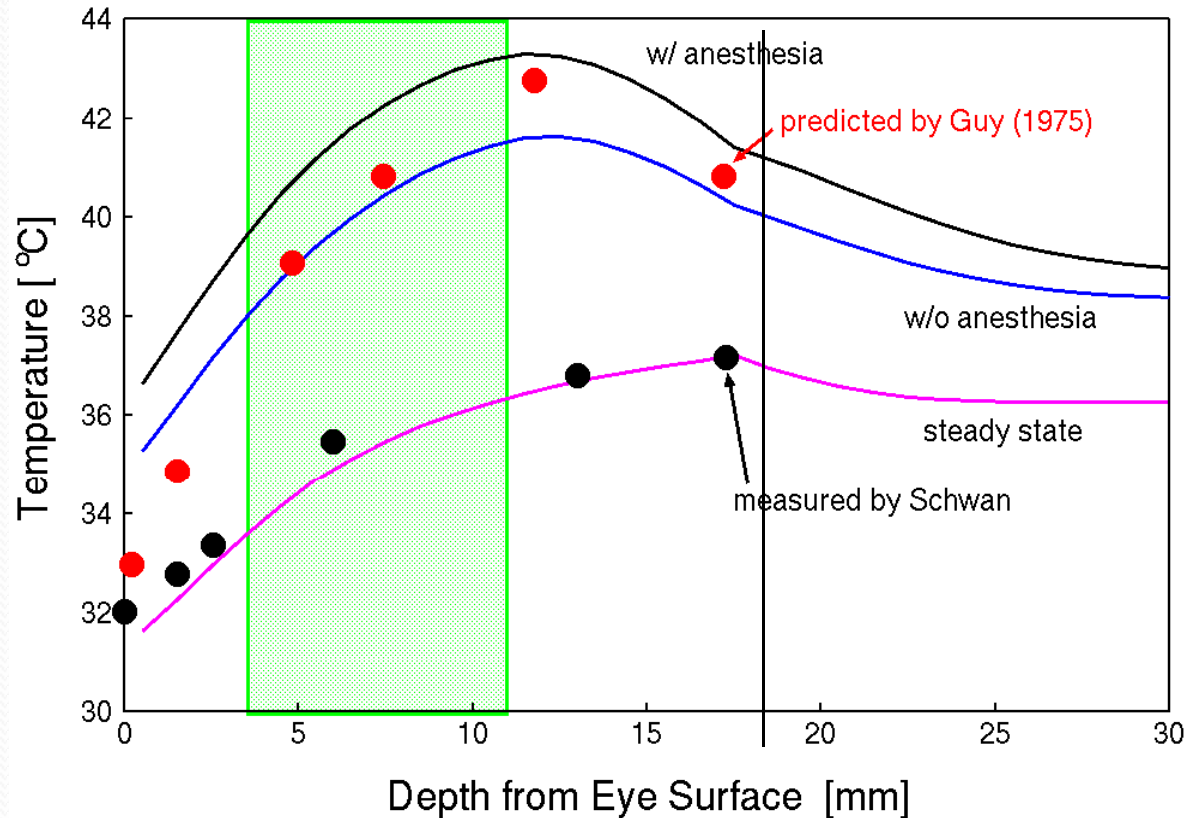
Cornea & Anterior Chamber

vitreous



Most dominant factor is **polarization**.

Comparison with Previous Studies

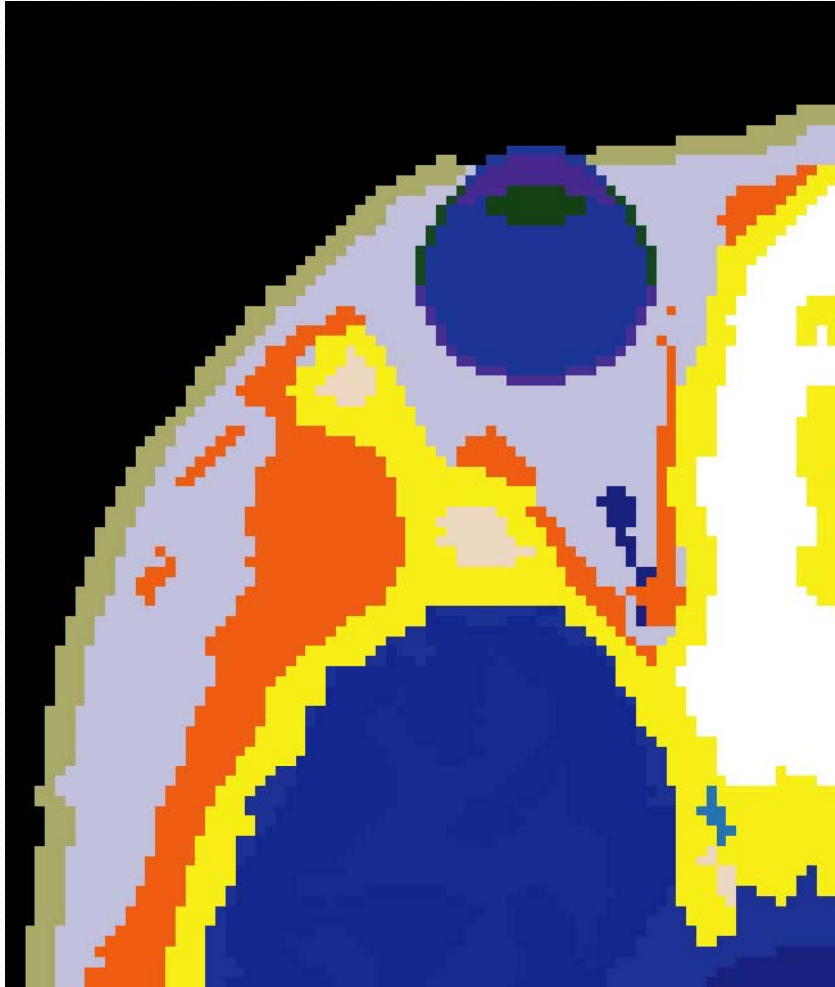


Eye-averaged SAR(3.1g)=61W/kg

Temperature elevation at posterior of Lens

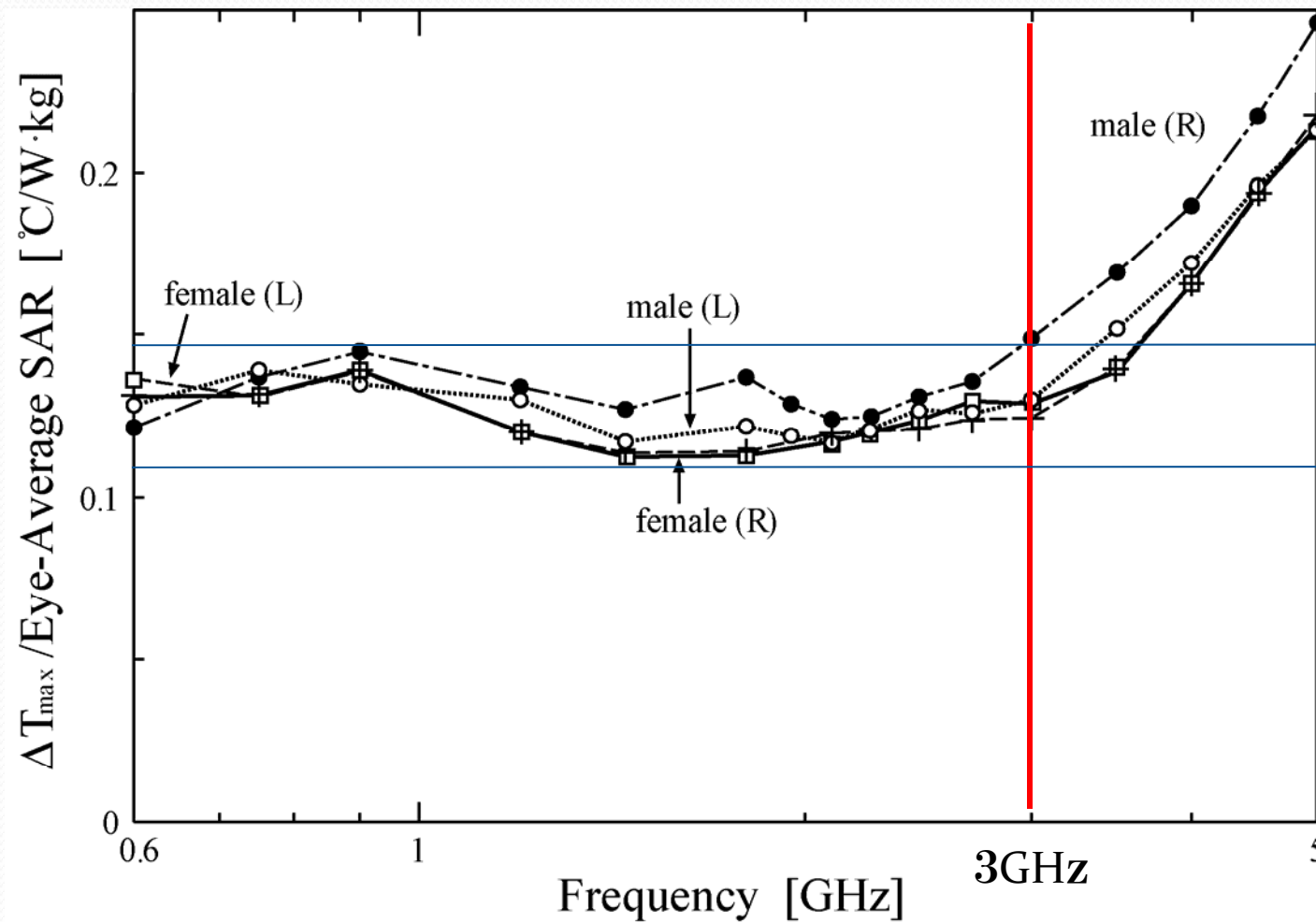
= 5-7°C (Dependent on the administration on anesthesia)

Temperature Elevation in Human Eye



- Anatomically-based human head model
- Resolution: 1mm (up to 5-6 GHz)

Relationship between Eye SAR and Temperature Elevation in Human Eyes



Summary for MW exposures

- No cataract is formed in non-anesthetized rabbit for 2.45GHz-MW exposure.
- Temperature in the rabbit's eye due to MW exposure does not reach threshold (42°C) without core temperature elevation.
- Thermophysiological modeling of human eye is needed, since core temperature does not elevate in the human for localized exposure.
- Eye-averaged SAR of the human (weight of eye: 10g) is a good measure for correlating temperature elevation up to 3 GHz, while not **above 3 GHz**.

Comparison of Different Guidelines /Standard @MMW

	Power Density Spatial Average	Power Density Spatial Max.	Ave. Time
IEEE	10 W/m ²	200 W/m ²	3 min
ICNIRP	10 W/m ²	200 W/m ²	0.7 min

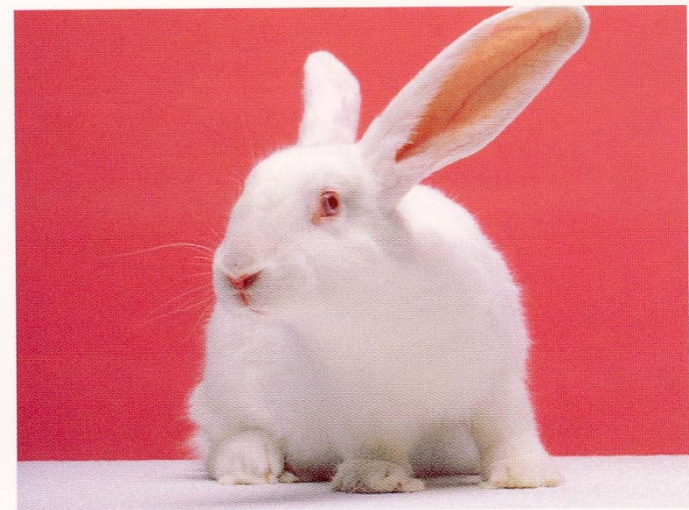
* Allowable power density at MMW in Japan is 20 W/m² for averaging time of 6 min.

Differences between Guidelines @MMW

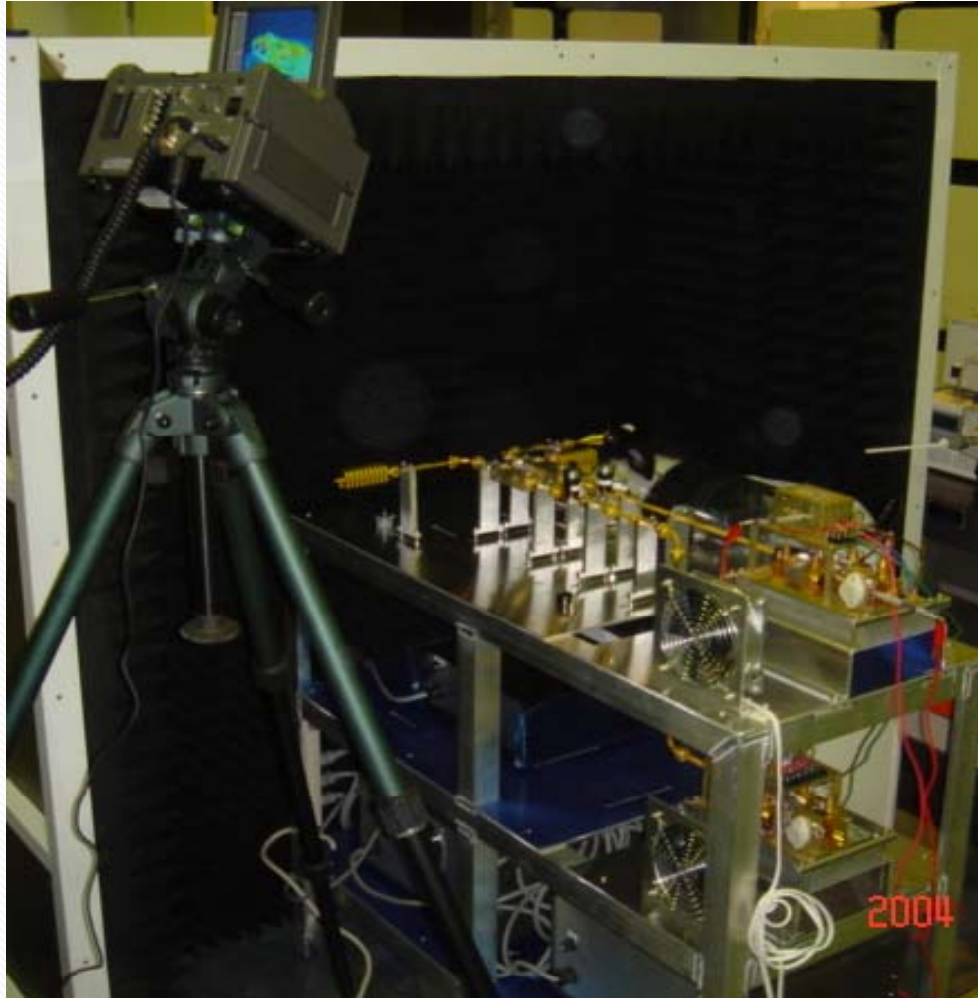
- In Japanese Guidelines, allowable incident power density to the eye in the MMW region is smaller than that in the other parts .
- **Inflammation of cornea (keratitis)** was observed at 35 and 100 GHz for the power density of 1,000 W/m² [1].
- Research on eye dosimetry at MMW is insufficient.

[1] J. S. W. Rosenthal, et al, *HEW Pub (FDA)*, 1976

- Averaging times in the guidelines/ standards are different with each other.

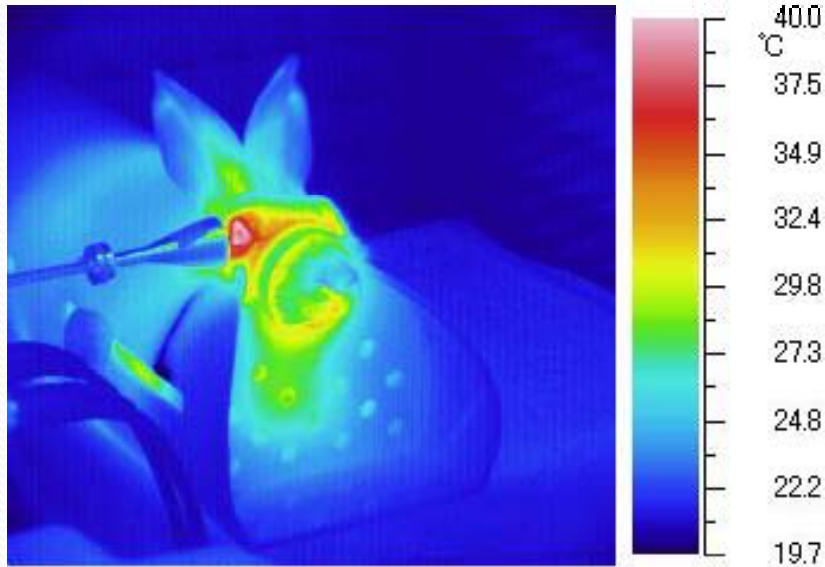


Experimental Setup (a horn antenna)



M. Kojima et al, *Health Phys.*, 2009

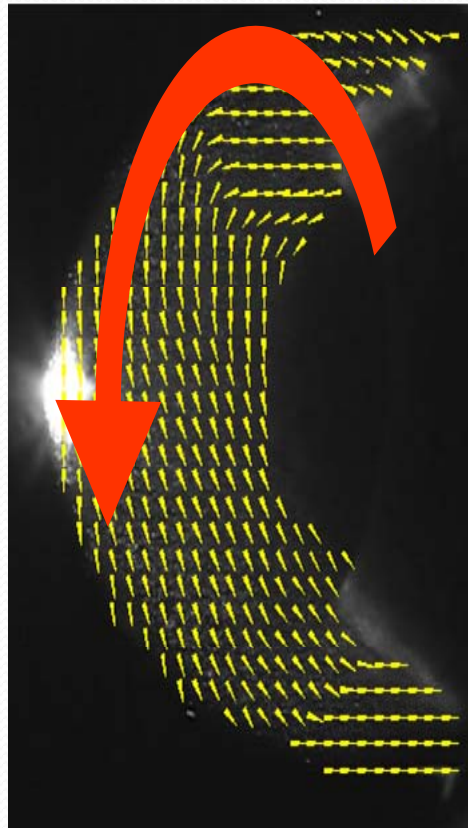
Eye exposure to MMW



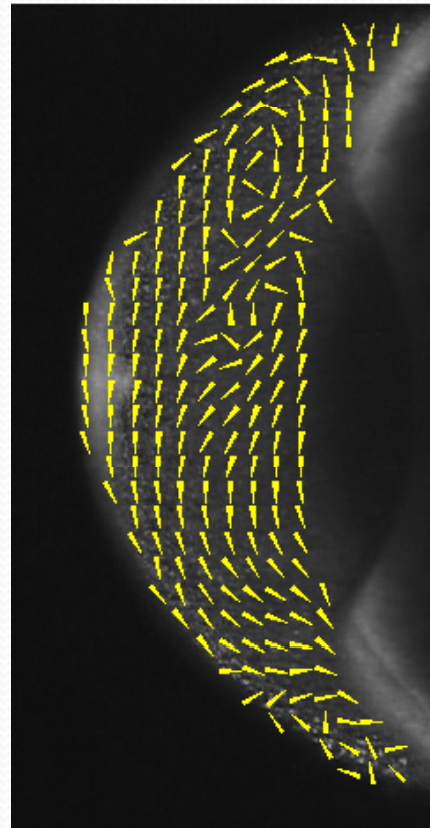
Facial burning was observed without injury in the eye.

Convection vectors in Eye

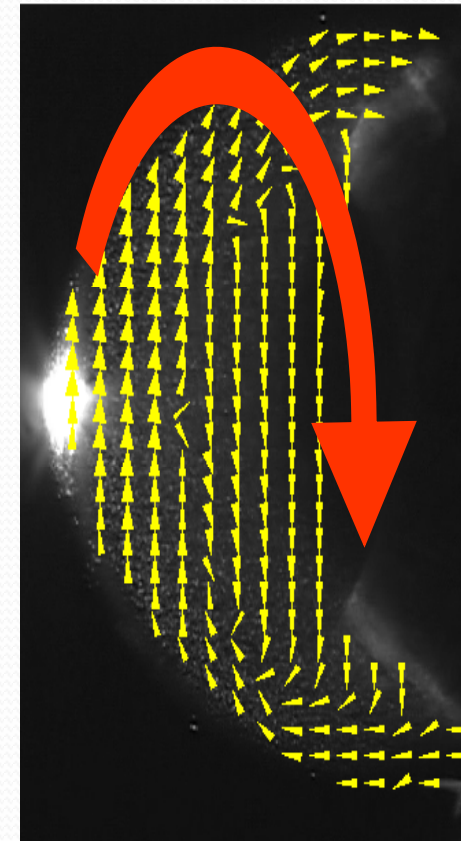
Arrow head size indicates flow speed: $\triangle > \Delta$



Before Exposure



18 GHz
After Exposure



40 GHz
After Exposure

Summary for MMW Exposures

- ❑ The frequency response and **the convection of aqueous humor** may take part in the thermal transport in the eye for MWW-induced heat cataract.
- ❑ Facial burning around the eye appears before ocular injuries.