

**COMSOL  
CONFERENCE**  
2018 LAUSANNE

# VIRTUAL PROTOTYPING OF UV-LED BASED POINT-OF-USE WATER DISINFECTION UNIT

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Paw Juul

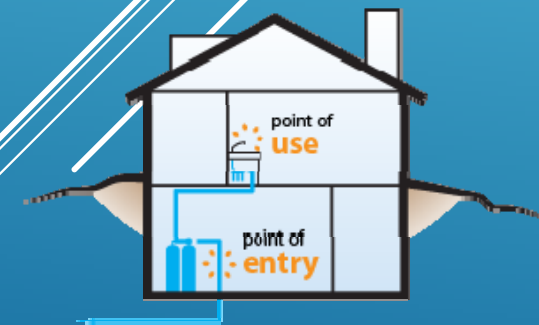
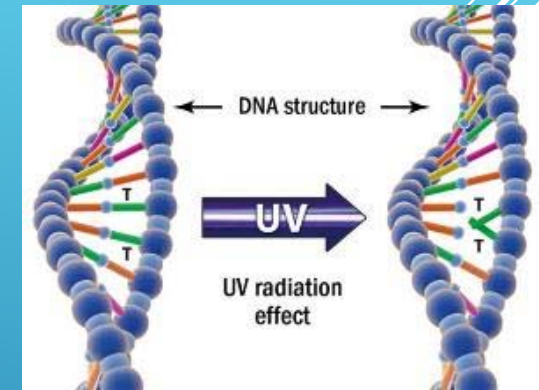
Liqtech Systems, Denmark



# LiqTech

# UV-LED DISINFECTION – POINT-OF-USE APPLICATIONS

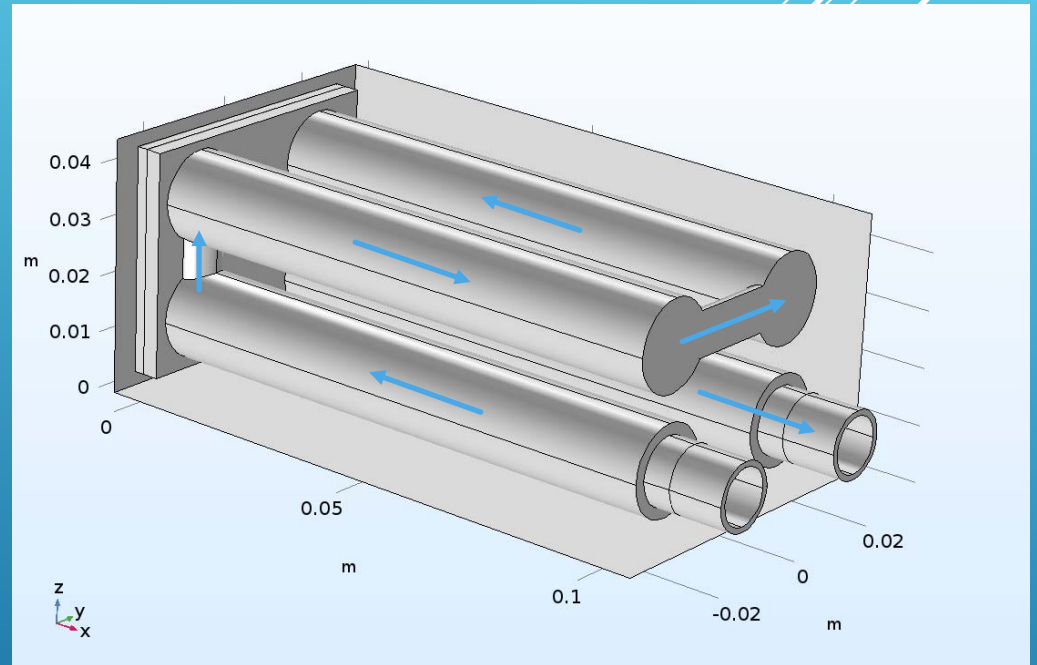
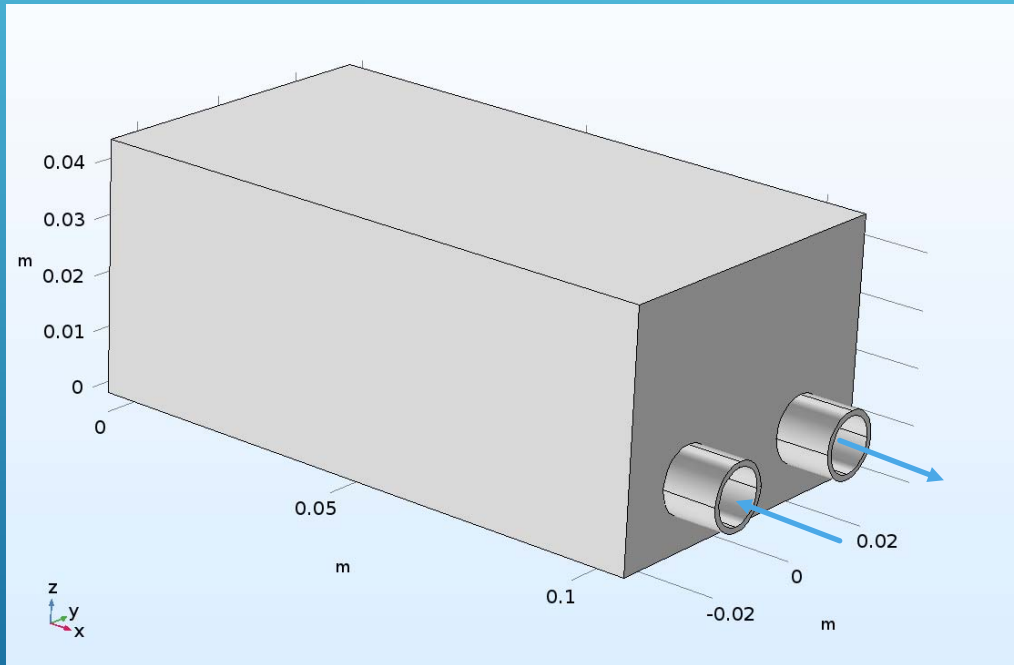
- UV LED is new technology
- Advantages compared to conventional mercury lamps
- No mercury
- On/off operation
- Immediate power up
- Flexible design due to size
  - => Ideal for point-of-use applications
- BUT...power conversion efficiency is (still) low
  - => High demands to reactor design



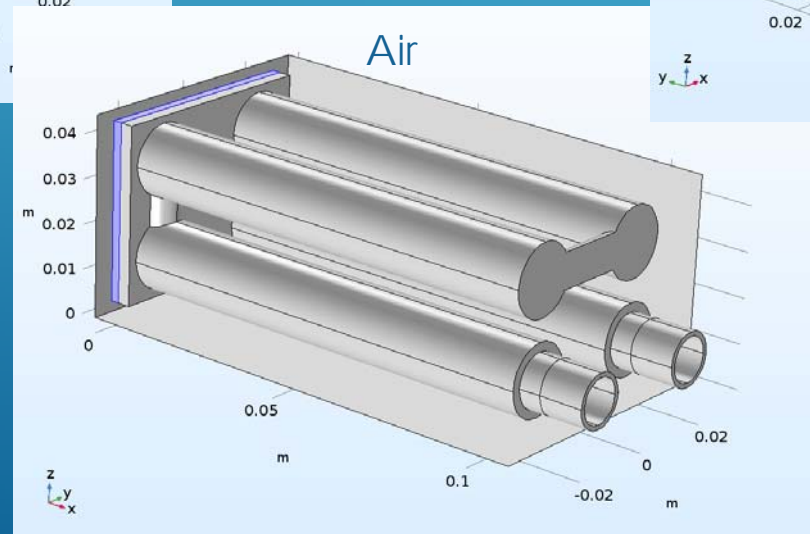
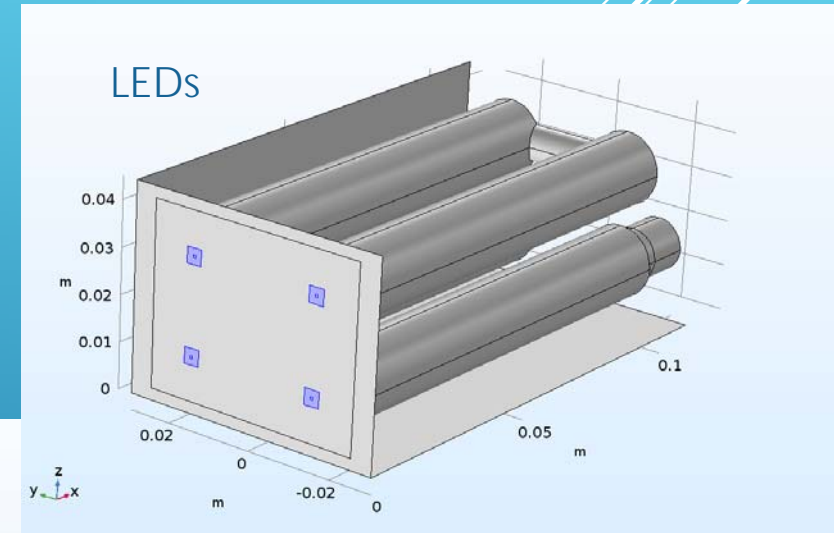
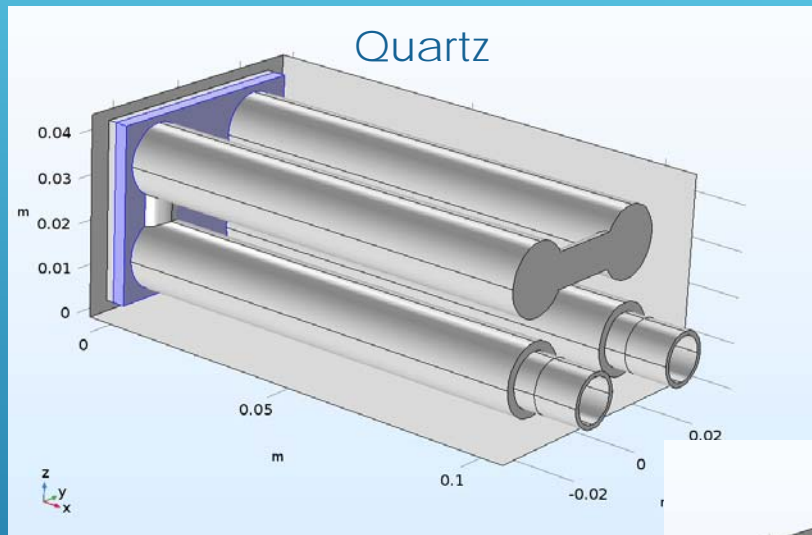
# REACTOR DESIGN AND TESTING

- Conventional design approach is physical prototyping and biological test
  - => Time consuming and expensive
- Virtual prototyping - faster and cheaper
- In the following – showcase models of the approach

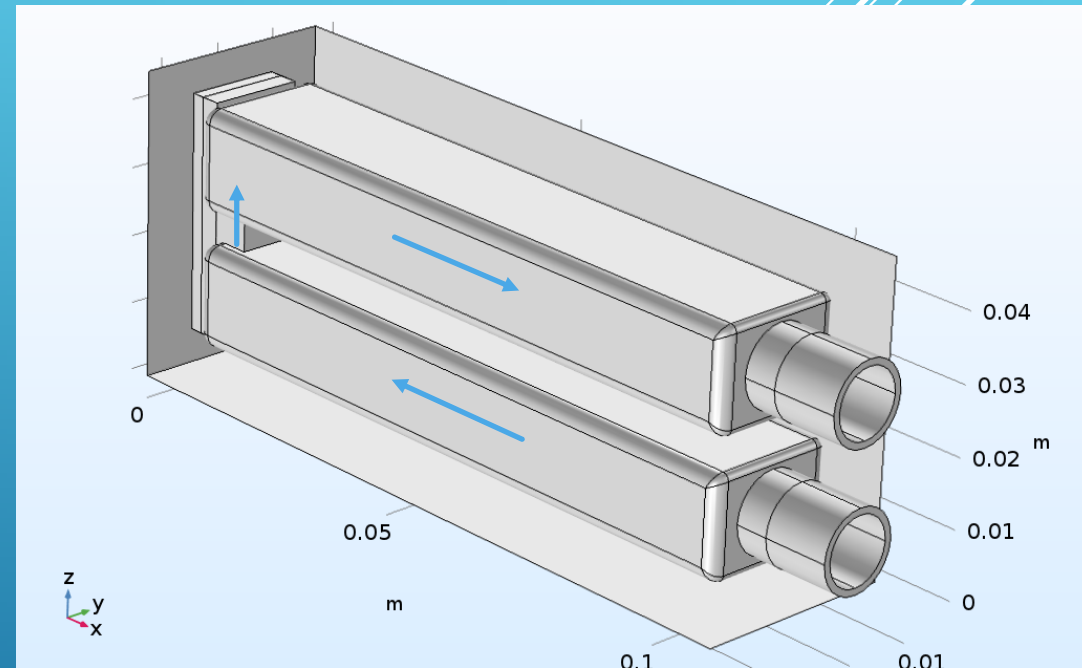
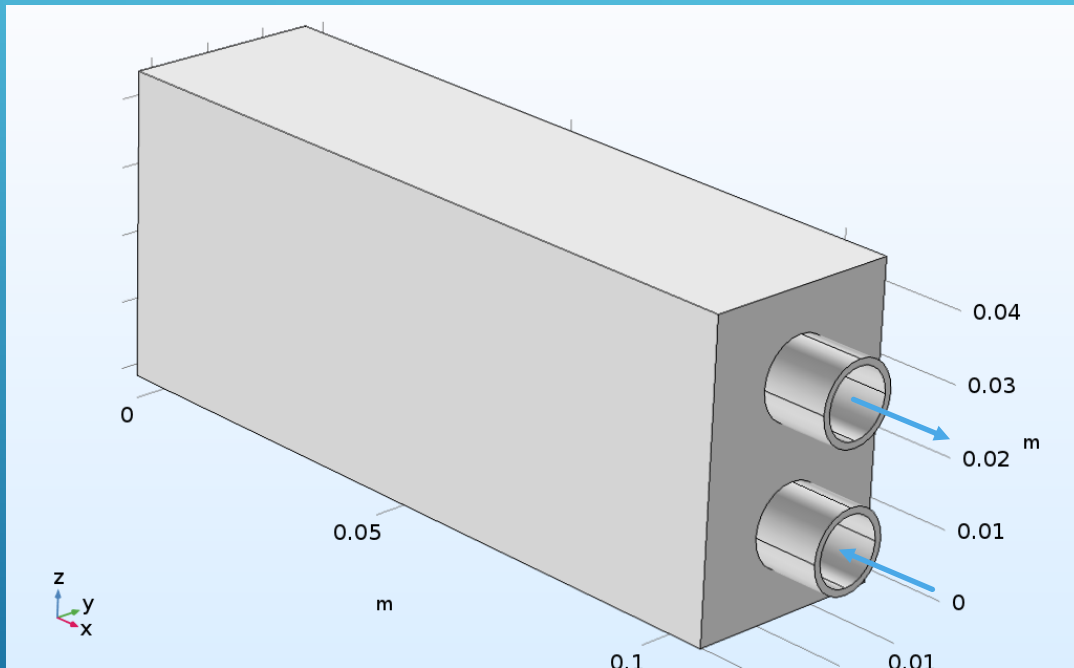
# SHOWCASE DESIGN - CYLINDRICAL



# SHOWCASE DESIGNS - CYLINDRICAL

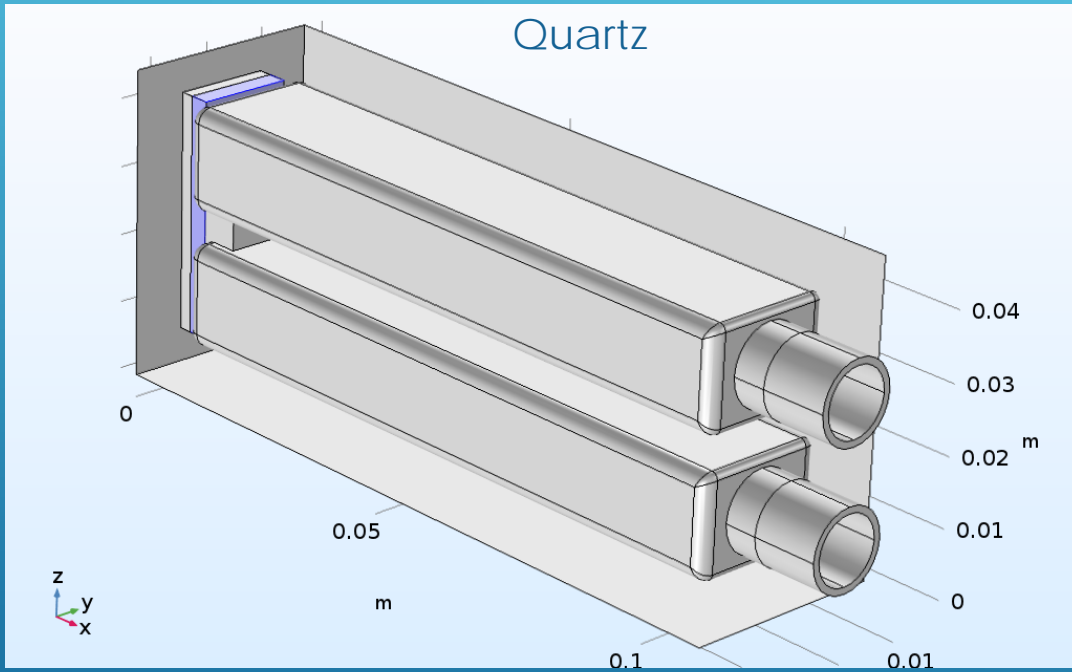


# SHOWCASE DESIGNS - RECTANGULAR

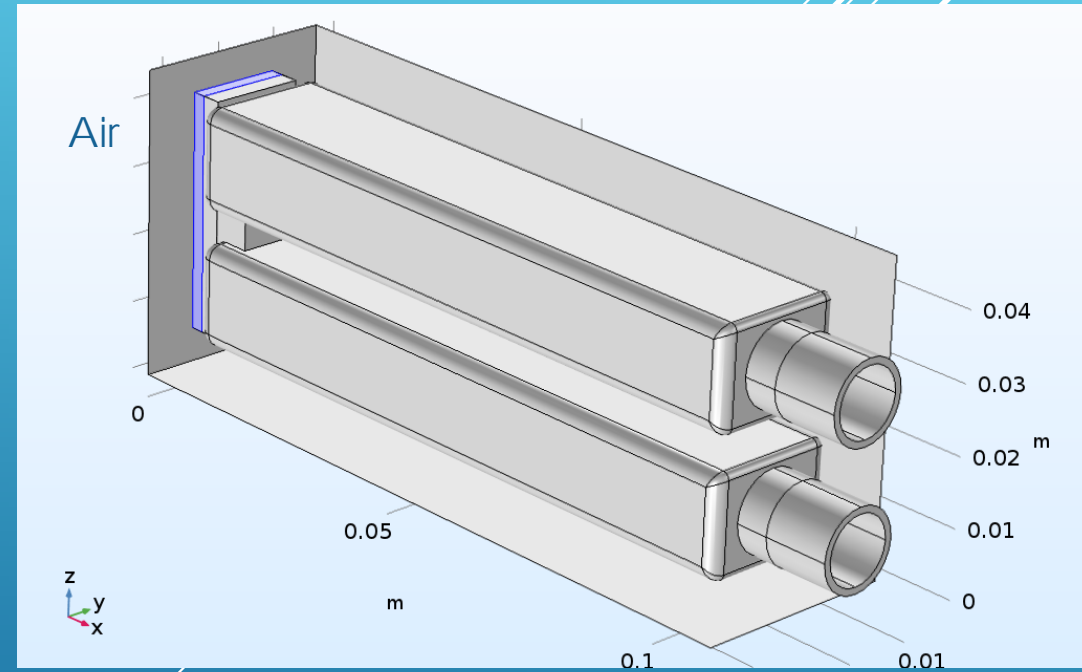


# SHOWCASE DESIGNS - RECTANGULAR

Quartz

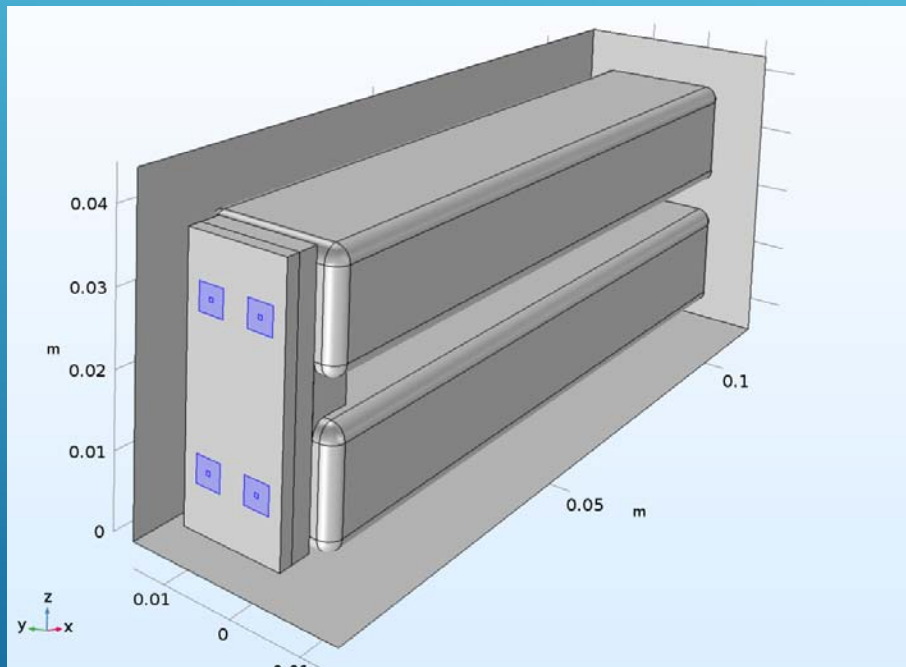


Air

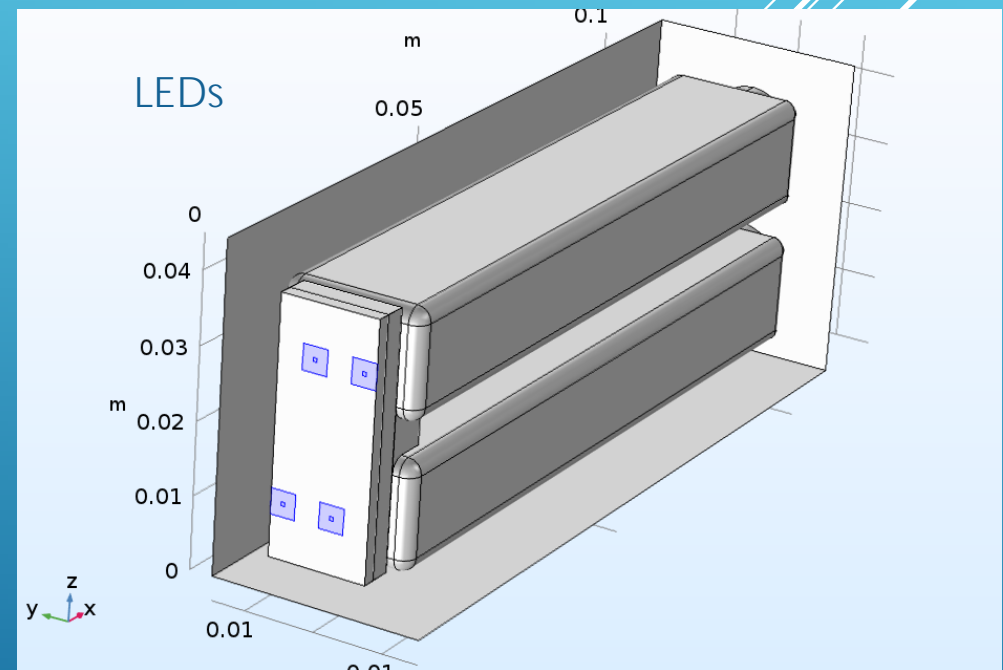


# SHOWCASE DESIGNS - RECTANGULAR

Symmetric position

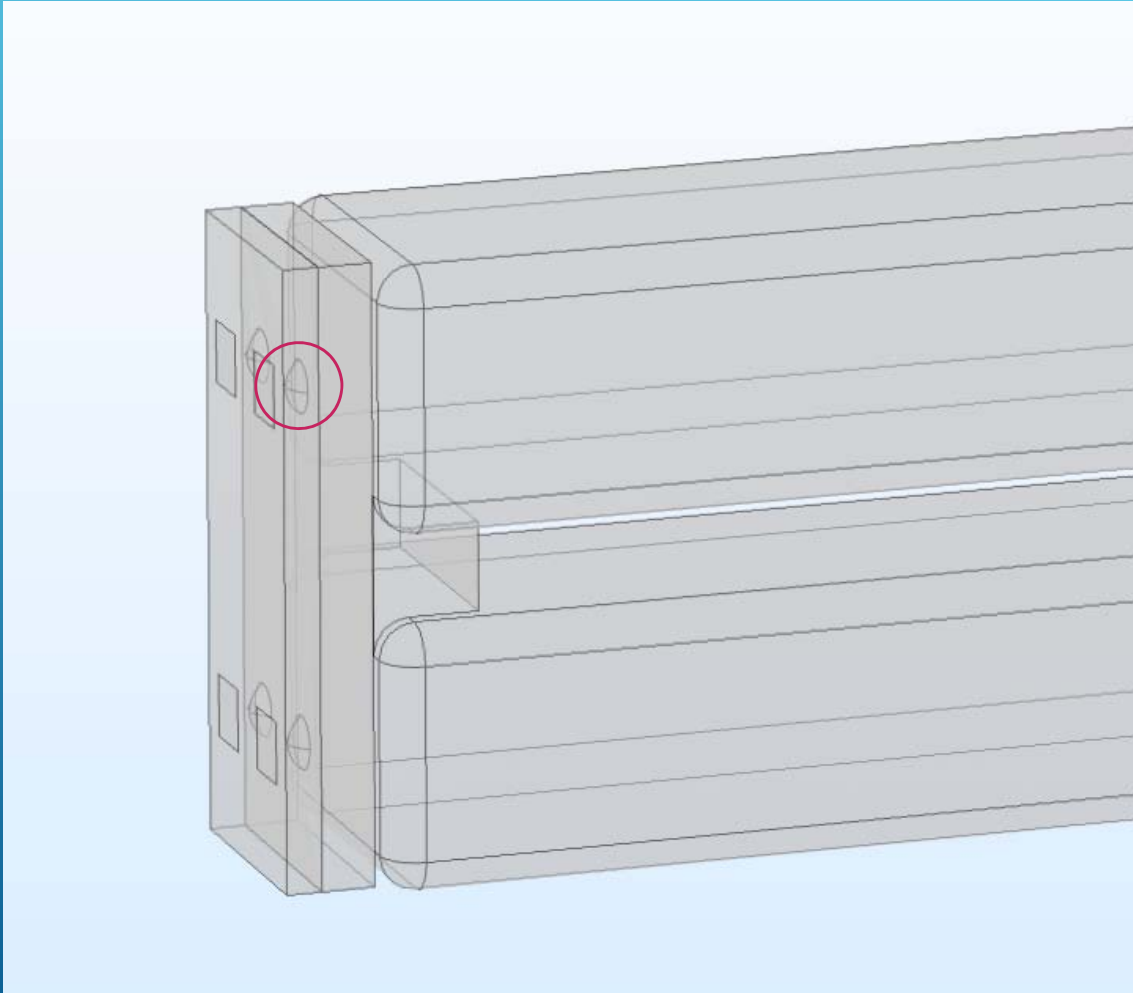


Shifted position





# SHOWCASE DESIGNS - OPTICAL LENS



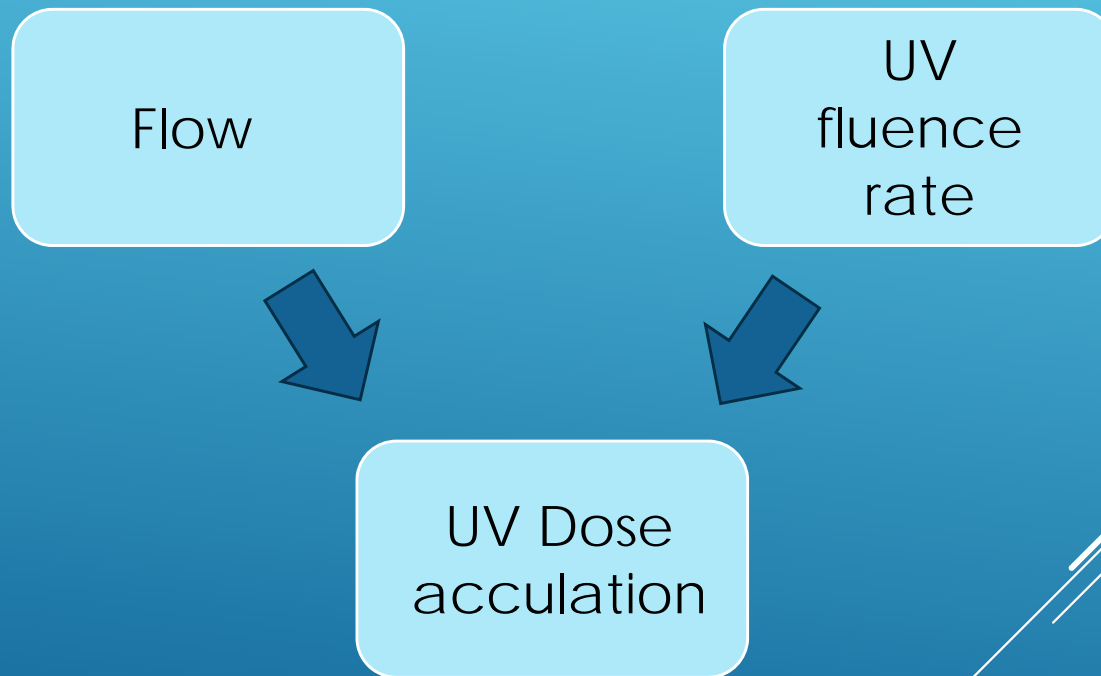
# MODEL SCENARIOS

Reactor	LED position	Surface	UVT	Optical lens
Rectangular	Symmetric	Non reflective	90%	No
Rectangular	Symmetric	Reflective*	90%	No
Rectangular	Symmetric	Non reflective	90%	Yes
Rectangular	Shifted	Non reflective	90%	No
Rectangular	Shifted	Reflective*	90%	No
Cylindrical		Non reflective	90%	No
Cylindrical		Reflective*	90%	No
Cylindrical		Reflective*	80%	No

\* 25% specular, 75% diffuse, R=0.95 (teflon)



# MODEL SETUP

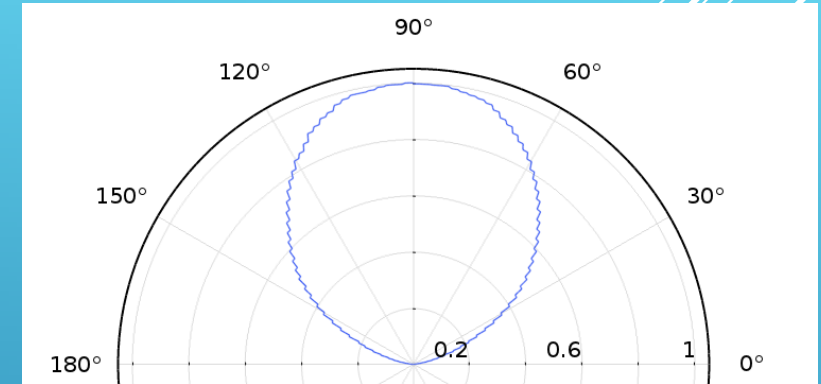


# MODEL SETUP - FLOW

- RANS k- $\epsilon$  model
- No slip boundary condition
- 0.1 m extra inlet and outlet pipes
- Fully developed inlet flow condition
- Zero pressure outlet condition
- $Q = 60 \text{ L/h}$
- $T = 20 \text{ }^\circ\text{C}$

# MODEL SETUP – UV FLUENCE RATE

- Ray tracing model (Geometrical optics)
- Refraction/reflection at interfaces
- LEDs considered point sources (35 mW, 265nm)
- Number of rays: 500.000 per LED
- Directional pattern obtained using photometric data import of ies file
- Fluence rate (F) is obtained using a domain accumulator

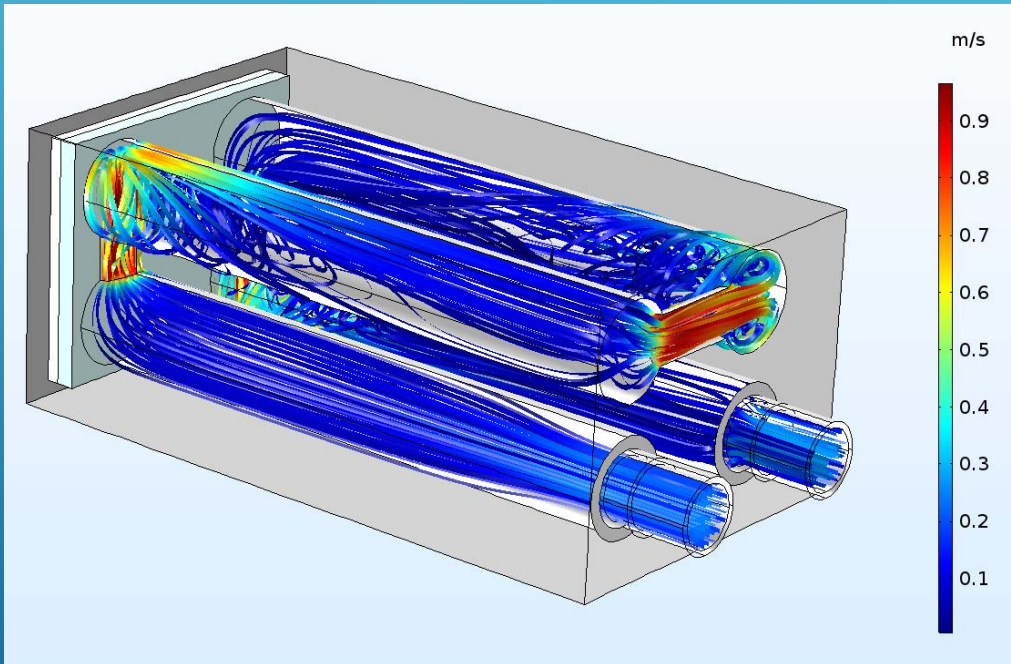


# MODEL SETUP – DOSE ACCUMULATION

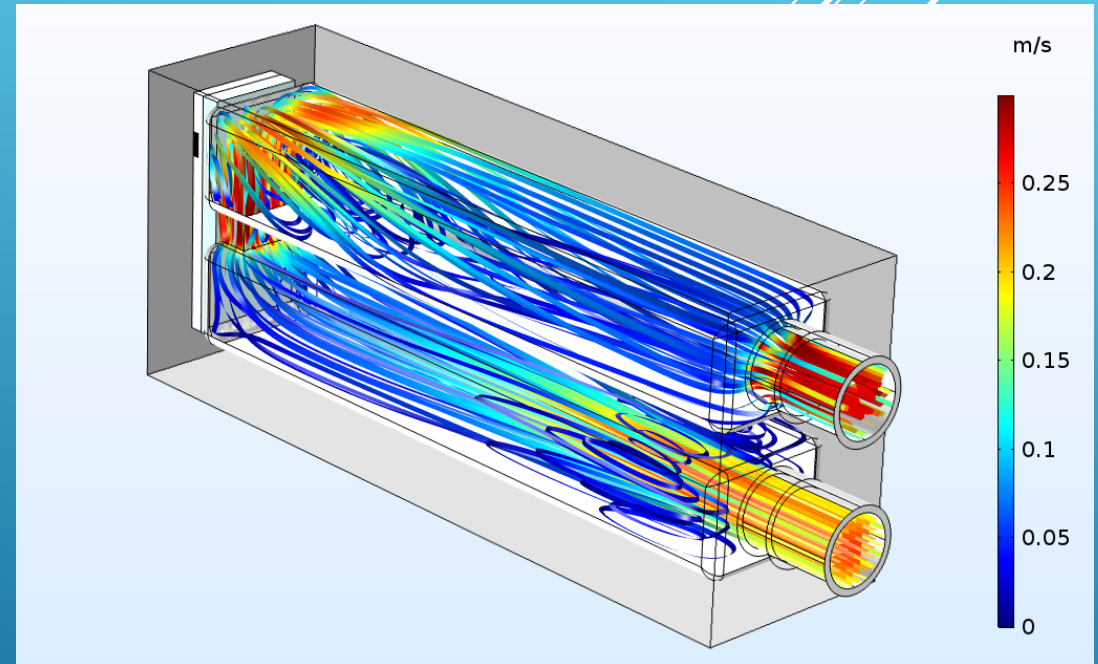
- Particle tracing using 10.000 particles
- Particle size 1  $\mu\text{m}$  (density 1025  $\text{kg}/\text{m}^3$ )
- Density at inlet proportional to velocity magnitude
- Transported by the flow field using Stokes drag
- Wall bounce condition
- UV dose accumulated as  $D = \int F dt$

# FLOW PATTERN

Cylindrical

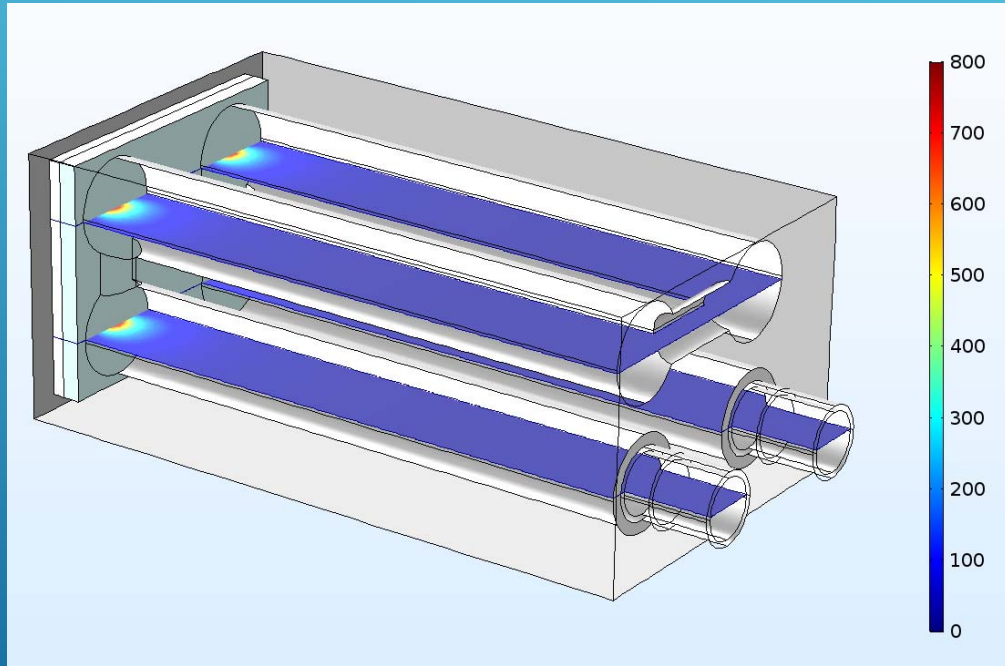


Rectangular

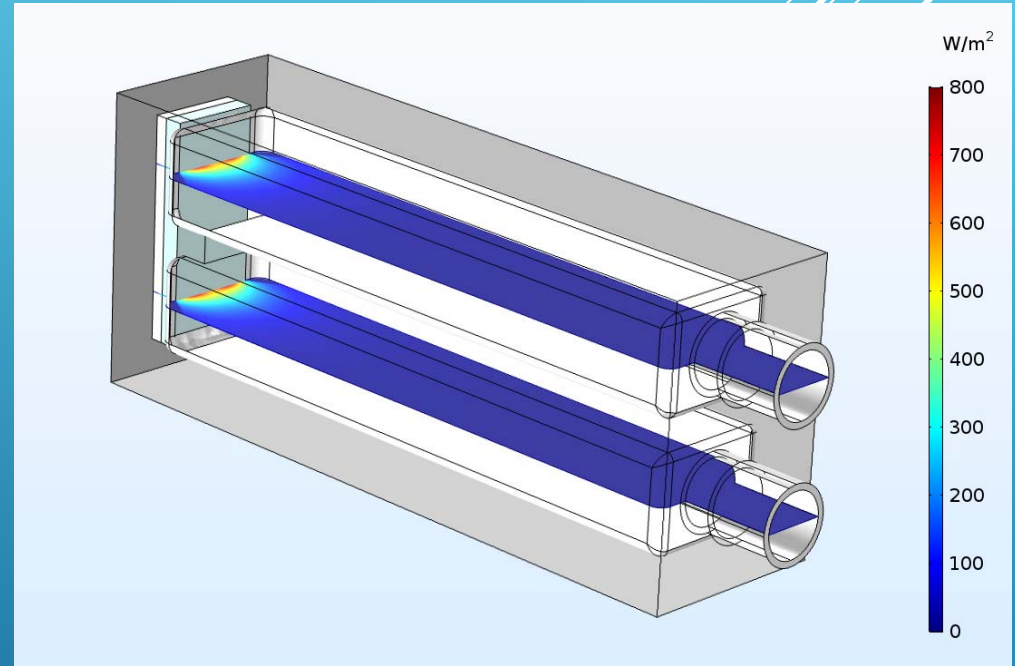


# UV FLUENCE RATE

Cylindrical non reflective



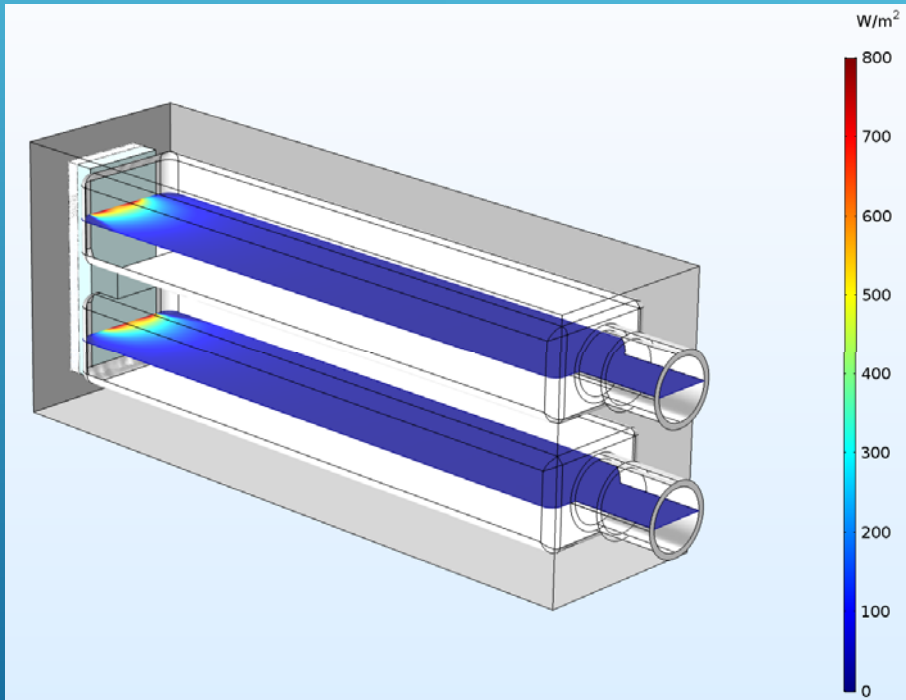
Rectangular (symmetrical) non reflective



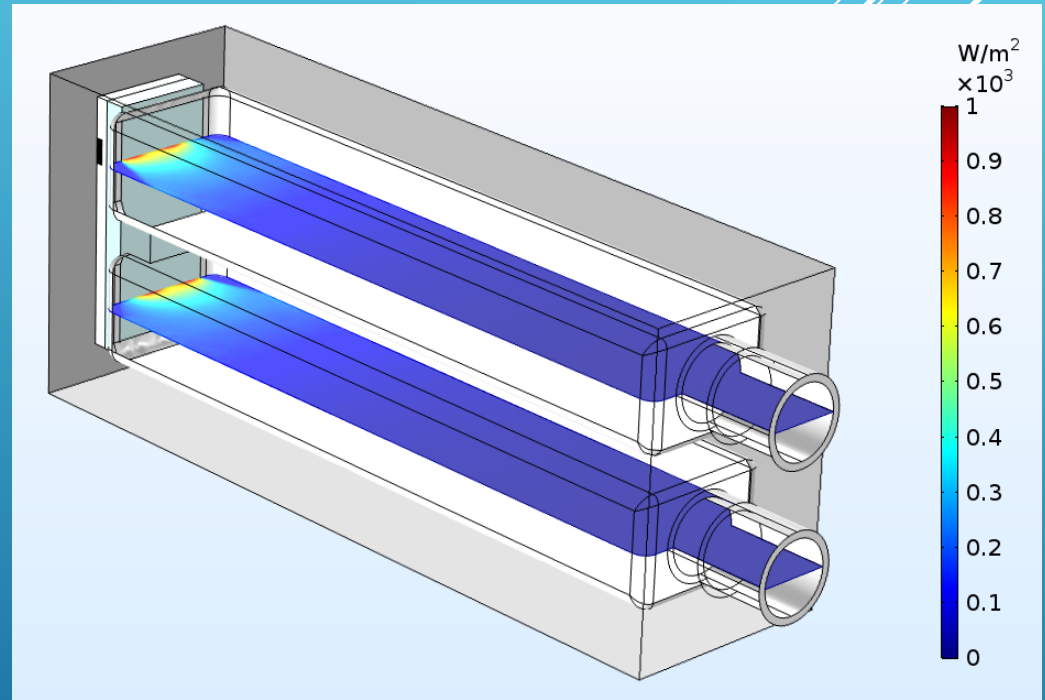


# UV FLUENCE RATE

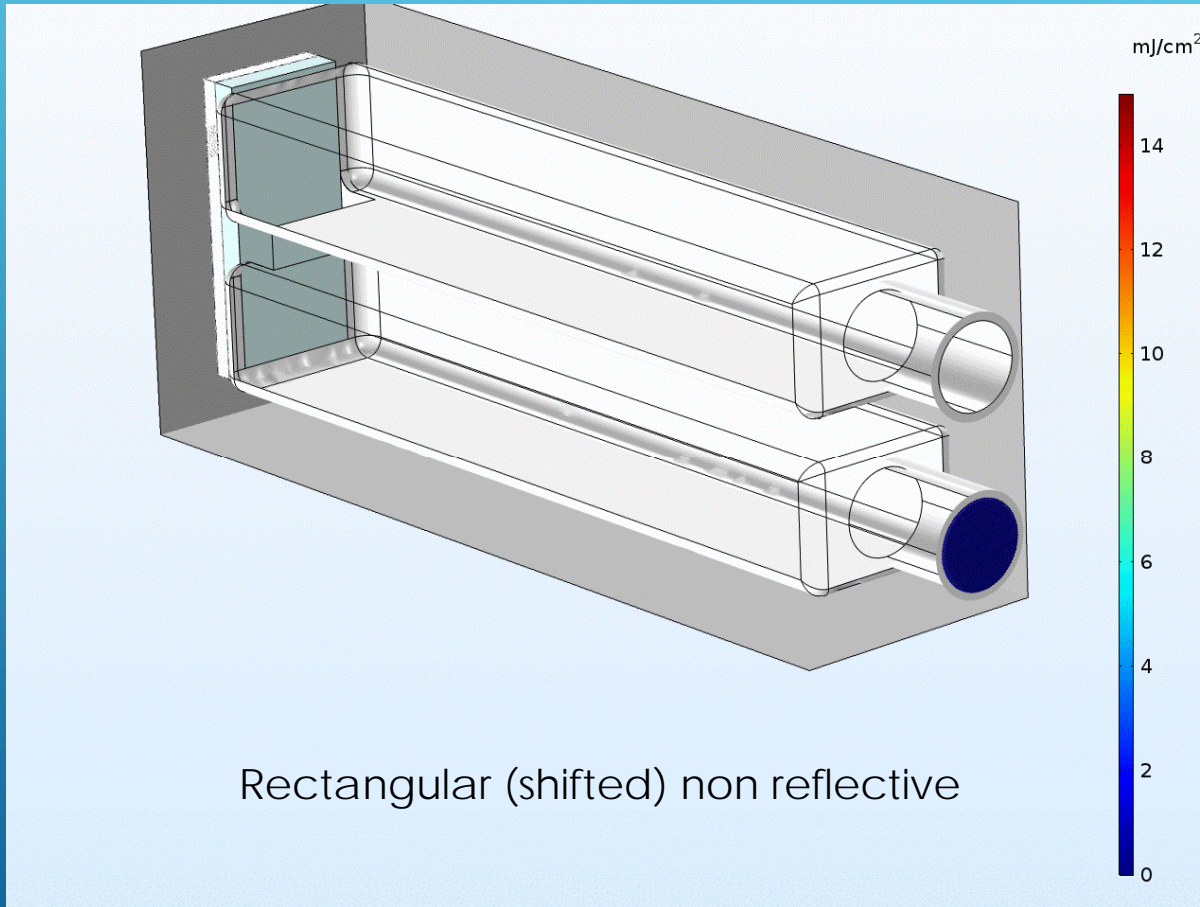
Rectangular (shifted) non reflective



Rectangular (shifted) reflective



# DOSE ACCUMULATION



Rectangular (shifted) non reflective

# DOSE DISTRIBUTION

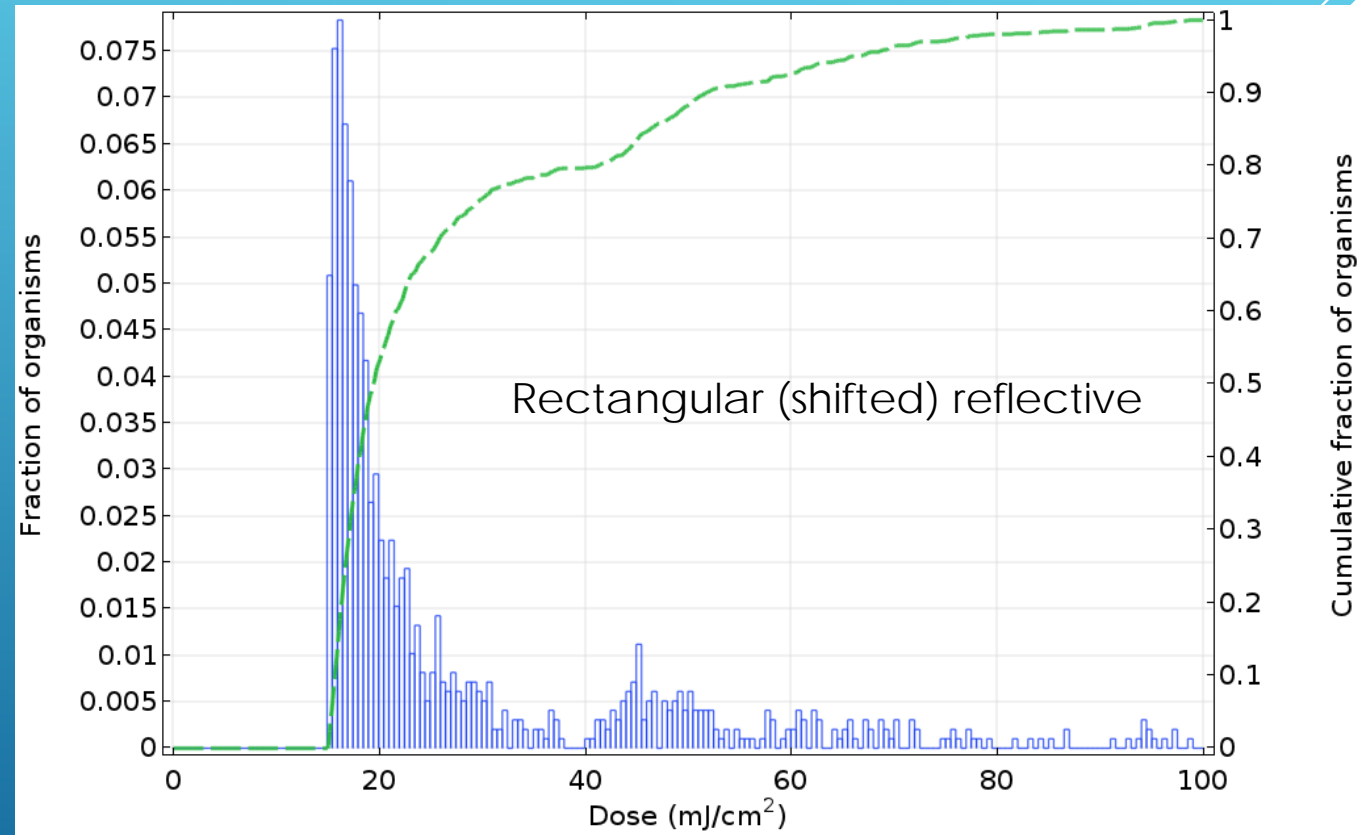
## 1<sup>st</sup> order inactivation

$$\frac{N}{N_0} = \exp(-kD)$$

$$\frac{N}{N_0} = \sum_i \exp(-kD_i)$$

## Reduction Equivalent Dose

$$RED = \frac{\ln\left(\frac{N}{N_0}\right)}{-k}$$



# REACTOR EFFICIENCY

Scenario	log I	RED [mJ/cm <sup>2</sup> ]
RECT-SYM- Non Reflective	1.66	7.19
RECT-SYM-Reflective	4.02	16.63
RECT-SYM-Non Reflective- Lens	2.48	10.26
RECT-SHIFT-Non Reflective	1.77	7.30
RECT-SHIFT-Reflective	4.32	17.85
CYL-Non Reflective-UVT90%	1.81	7.49
CYL-Reflective-UVT90%	5.85	24.21
CYL-Reflection-UVT80%	3.92	16.91

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Reflective surfaces are important

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Optical lenses can (partly) substitute reflective surfaces

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UV transmittance of water is important

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Shifted LED position outperforms the symmetrical



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The cylindrical design outperforms the rectangular



# THANK YOU FOR YOUR ATTENTION

## QUESTIONS?

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