UV LED water treatment systems and computational modelling

Prof. George Aggidis, Jainil Shah

Dr. Audrius Židonis

Dr. Olivier Autin

2nd February 2022

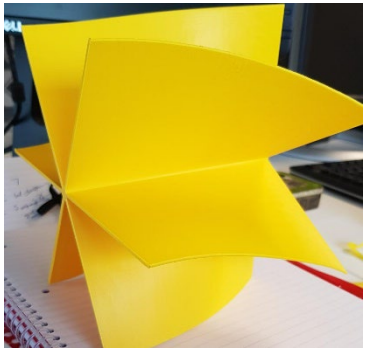
Agenda

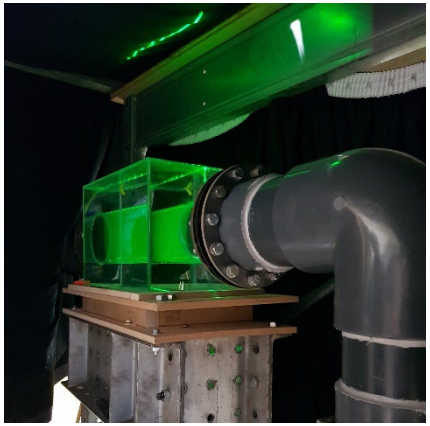
- Lancaster University and Typhon Treatment Systems
- Municipal UV LED Reactors for Water Disinfection
- Computational Modelling
- Case Study: Existing site retrofit
- Ongoing Research

Lancaster University

Lancaster University

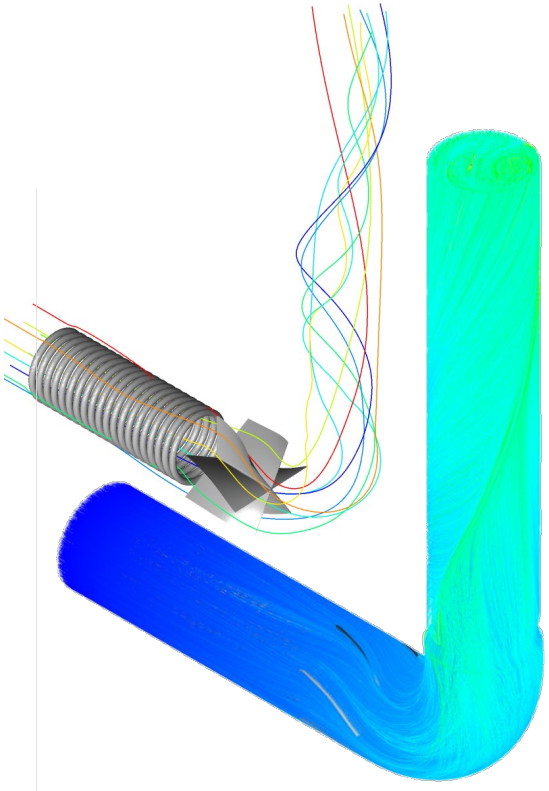
- **Research Facilities available at Lancaster University Energy Group**





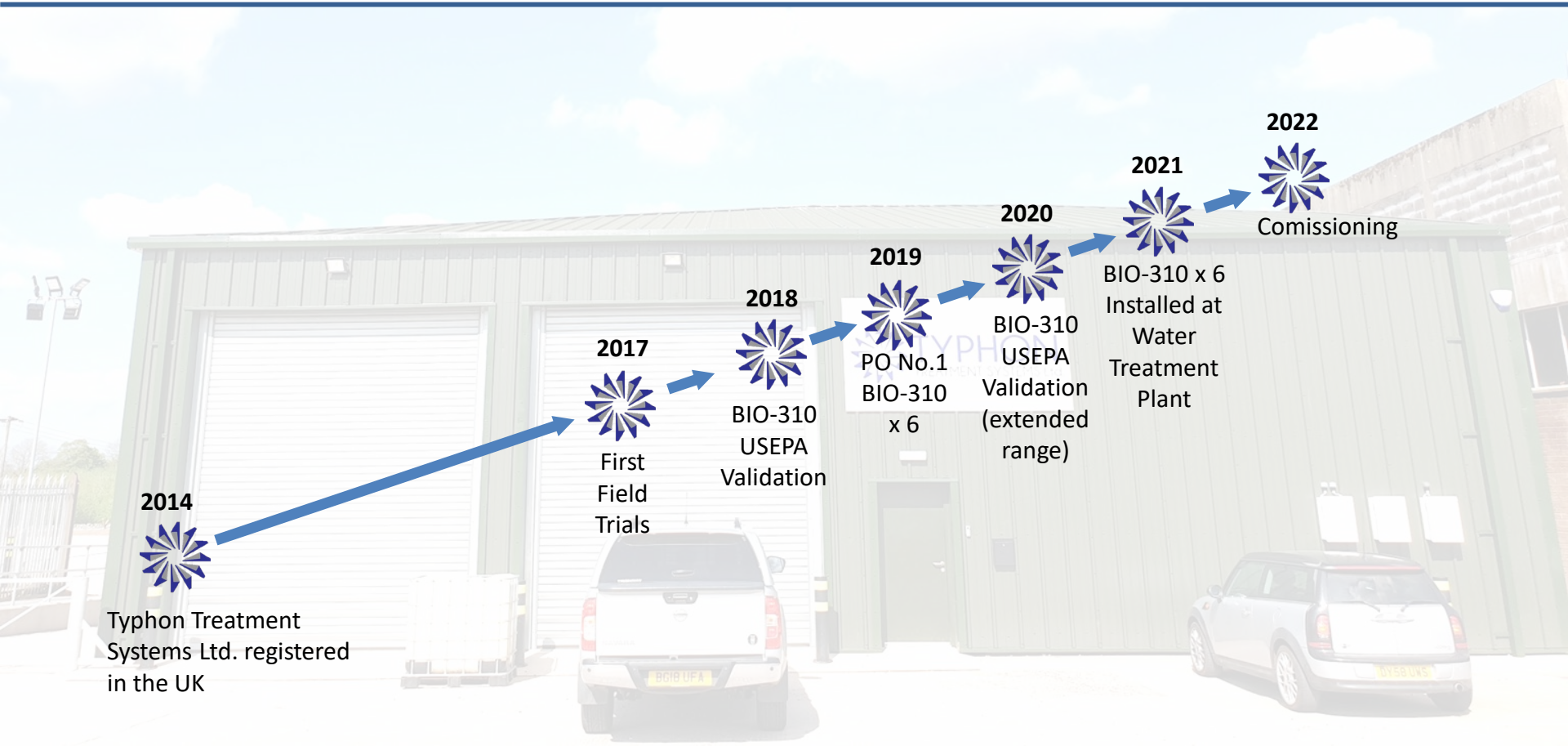
Lancaster University

- **Access to state of the art CFD software and high end computing (HEC) capabilities**



Typhon Treatment Systems

Typhon Treatment Systems

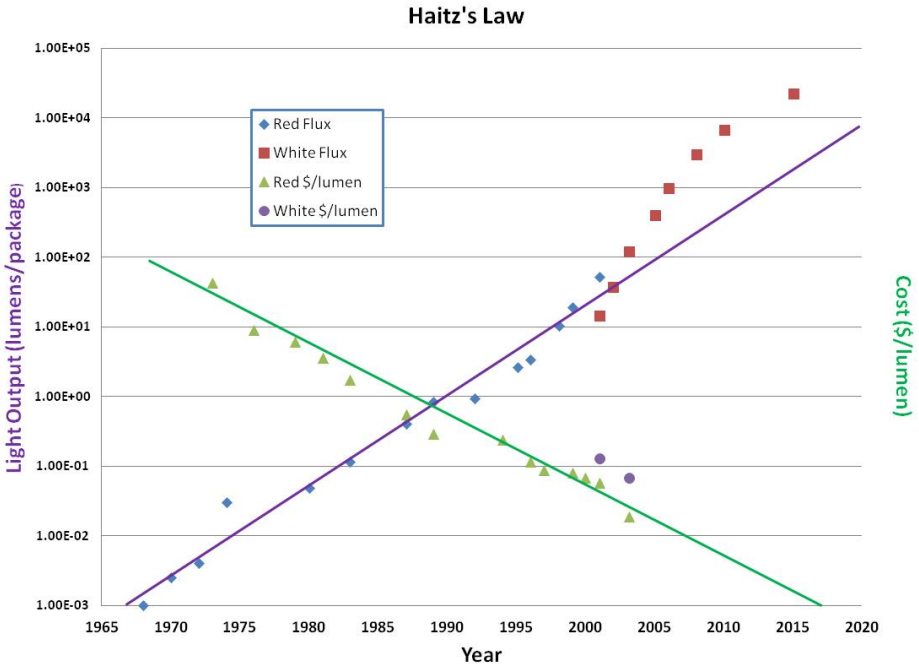


Typhon Treatment Systems

- Six-unit installation producing 36,000 m³/day
- World first UVC LED application
- Award winning project and product

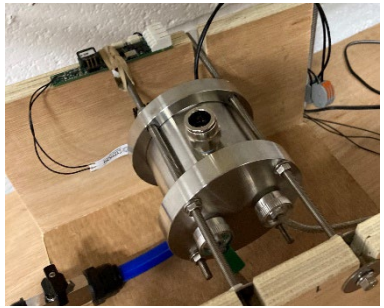
LED Technology

- A Light Emitting Diode (LED) is a semiconductor light source.
- The first LED's became available in 1962.
- Output performance 20x increase, and price 10x decrease *every 10 years*. (Haitz's Law)
- The original UV LED development came from the US Defence Dept in 2002.
- UV-C LED performance improvement is beating Haitz's Law.

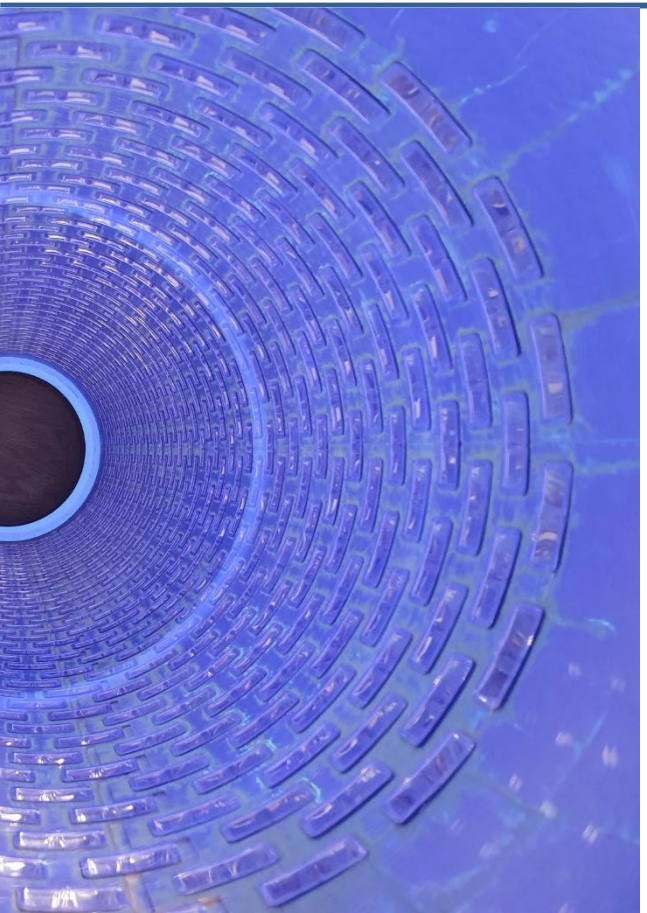


What Else?

- Wastewater treatment
- Wastewater reuse
- Advanced oxidation
- Measuring and monitoring
- Algal control
- Arctic steam drilling



USEPA UVDGM Validated UV LED



- **Typhon, BIO-310 UV LED Reactor**

  Designed for continuous high flowrate applications

- **Validated Range:**

  70 to 98% UV Transmissivity UVT_{1cm}

  28 to 501m^3/h (2,200 USGPM) Flowrate

  Up to 4 Log inactivation of:

  Cryptosporidium

  Giardia

  Adenovirus

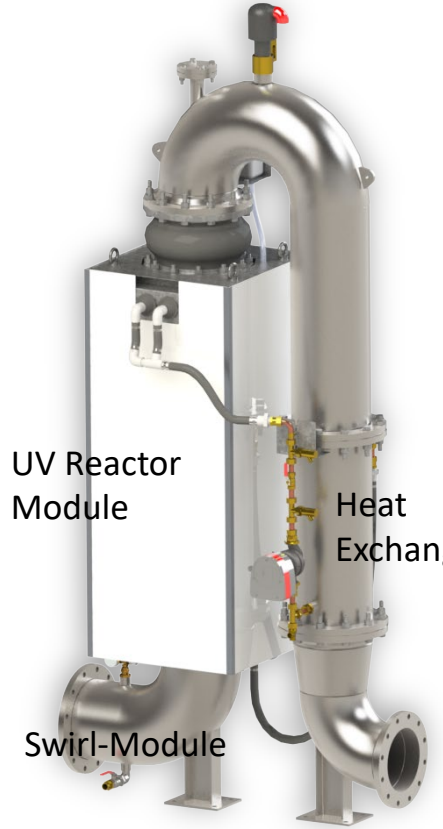
- **USEPA UVDGM validation in conjunction with:**

  Technologiezentrum Wasser (TZW)

  Carollo Engineers inc.

BIO-310 Reactor Design

300mm DIA, Completely Open, Quartz Tube

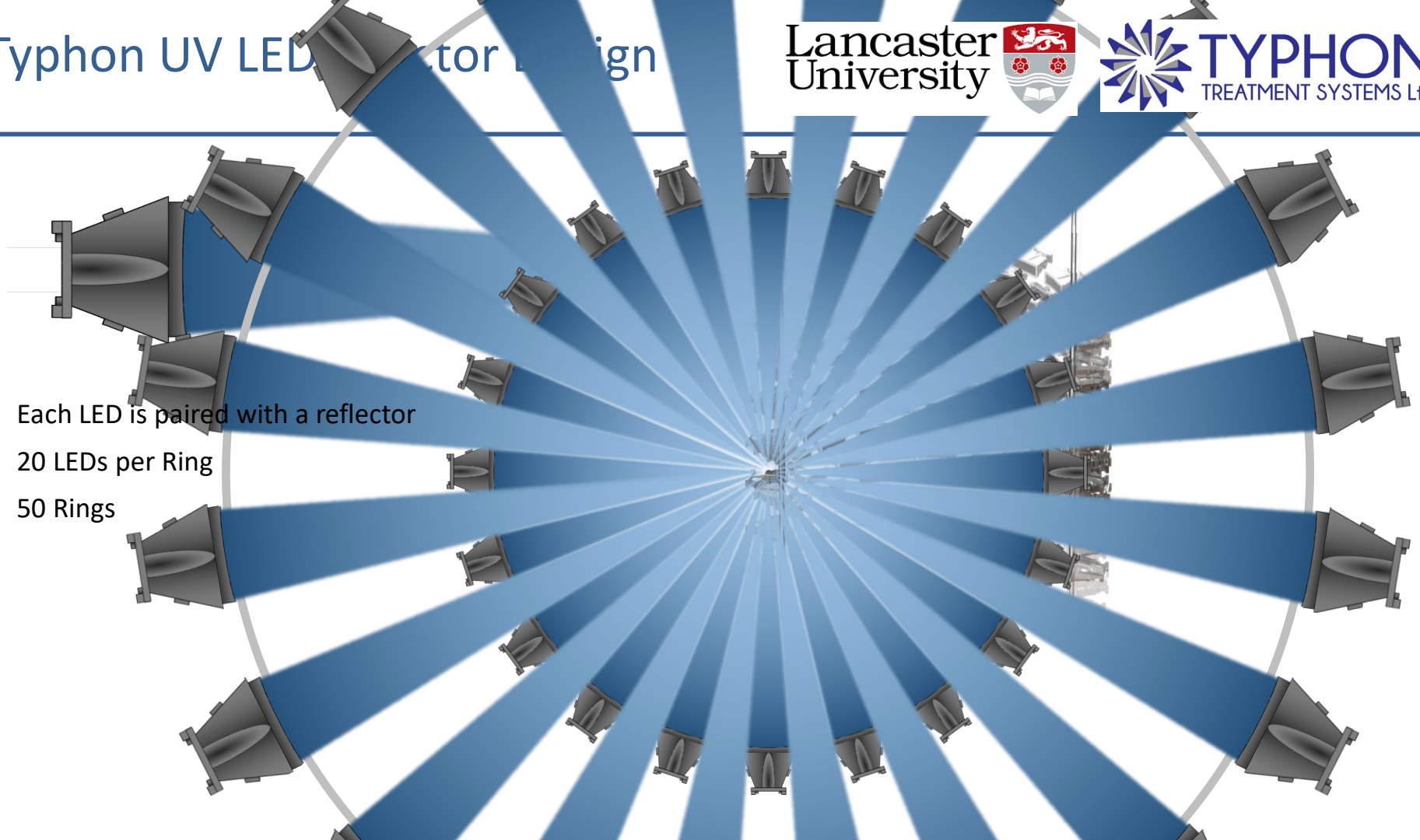


Optical cone system focuses the UV light from 1,000 LED's towards the reactor centre

Typhon UV LED [illegible]ctor [illegible]ign

Lancaster University

TYPHON TREATMENT SYSTEMS Ltd.

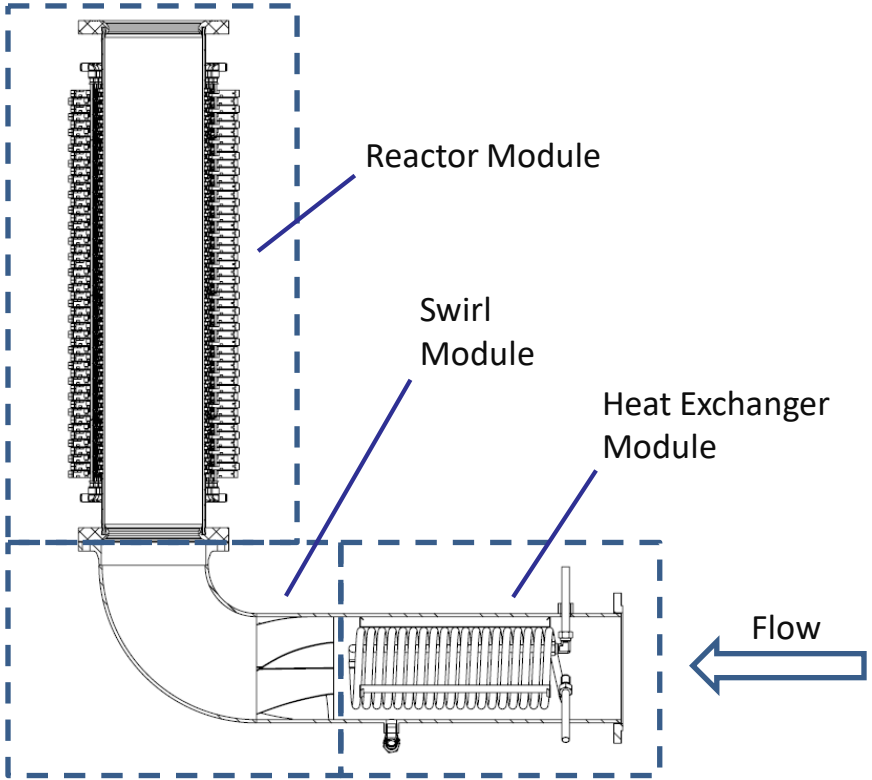


Each LED is paired with a reflector

20 LEDs per Ring

50 Rings

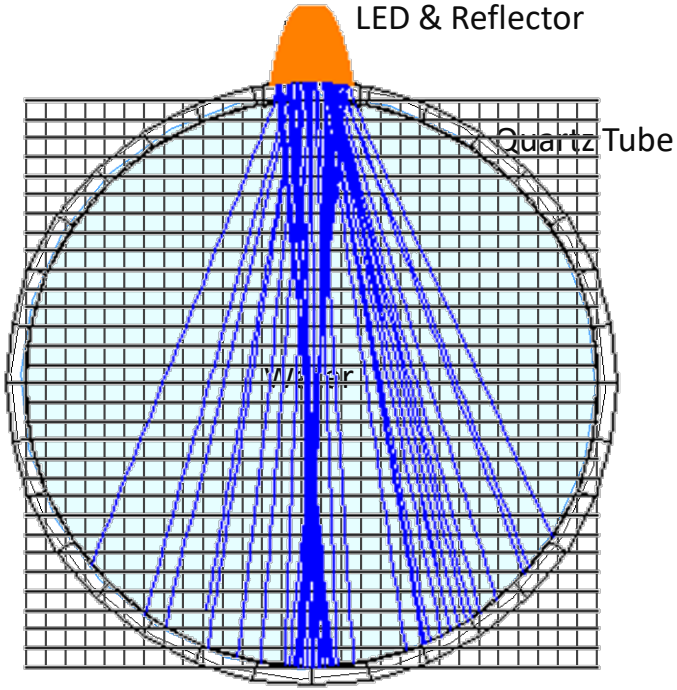
BIO-310 Validation Configuration

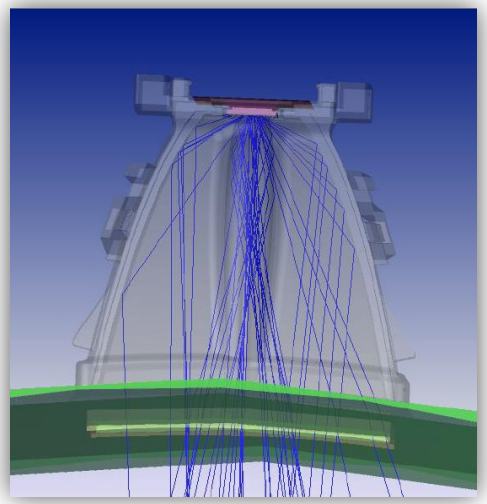


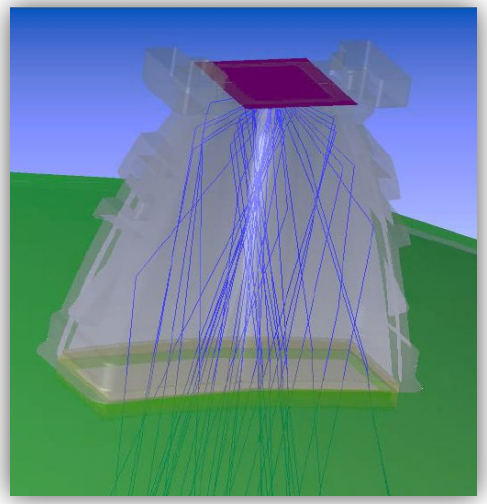
Validation Unit at TZW

Optical Modelling – Ray Tracing

Ray Trace modelling was performed on a single Reflector mounted on a segment of Quartz tube filled with Water at a constant UVT.





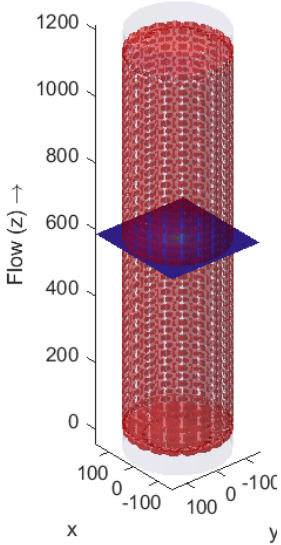


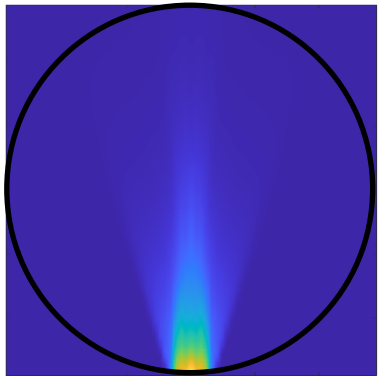
For clarity only a fraction of the Rays are shown

Optical Modelling – LID

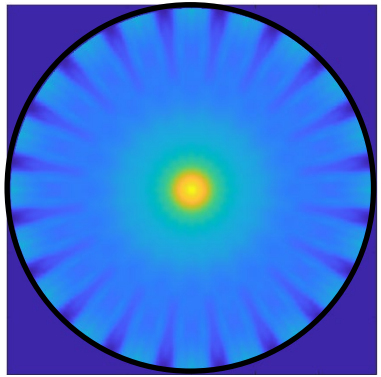
The Ray Trace model was then converted into Light Intensity Data (LID)

View down the Reactor (Perpendicular to Flow)

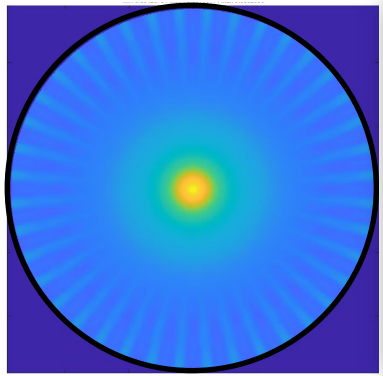




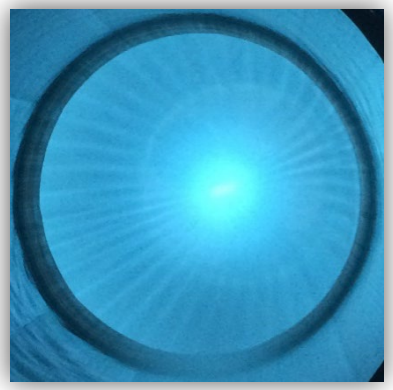
Single LED



Ring of 20 LEDs



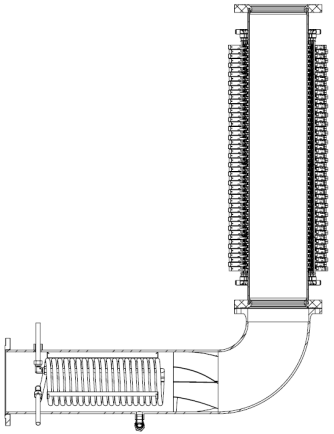
The complete Reactor with alternating rings



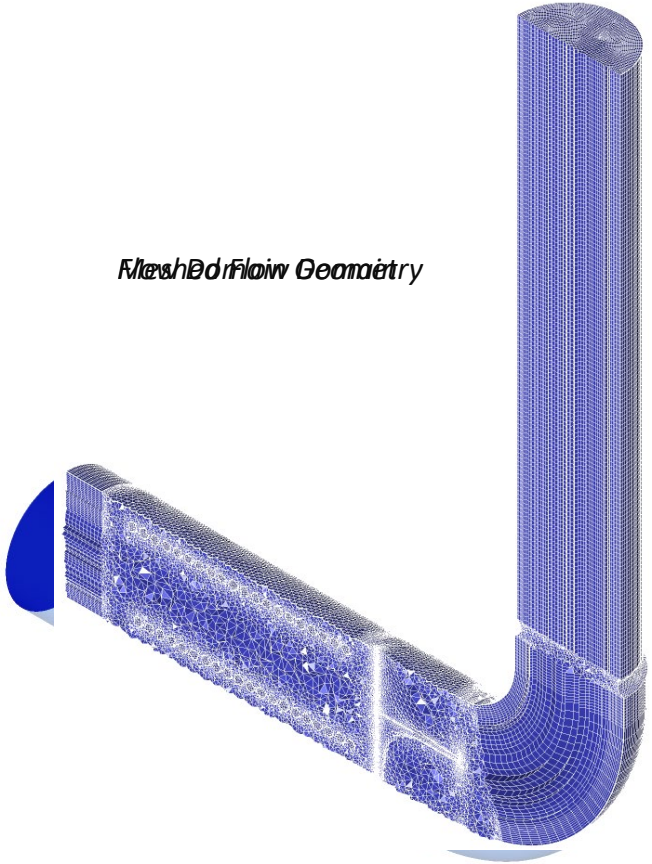
A photograph of the actual reactor

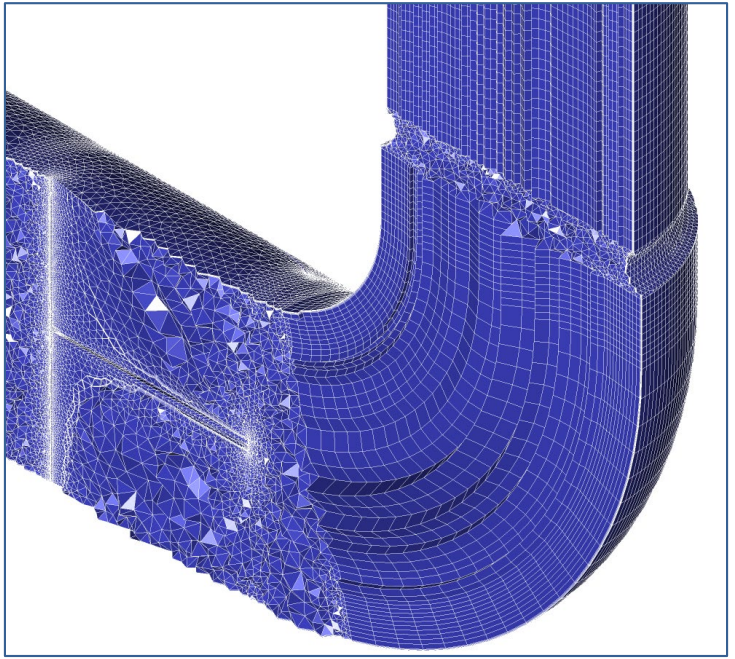
CFD Modelling – Hydraulic Geometry

Section View of Reactor Unit



Meshed Flow Geometry



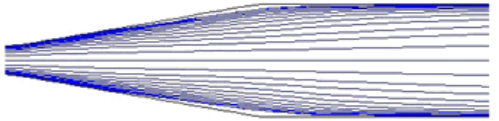


CFD Modelling – Setup

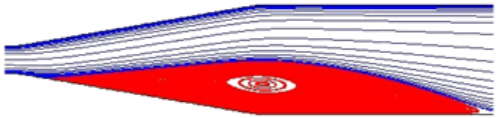
- **Flow is fully turbulent**
- **Flow conditions are statistically Steady State**
- **RANS Turbulence Models are appropriate**

  (Reynolds-Averaged Navier-Stokes equations)
- **k-ω Shear Stress Transport (k-ω SST) to capture flow separation**

Standard k-ε fails to predict separation



Shear Stress Transport (SST) model

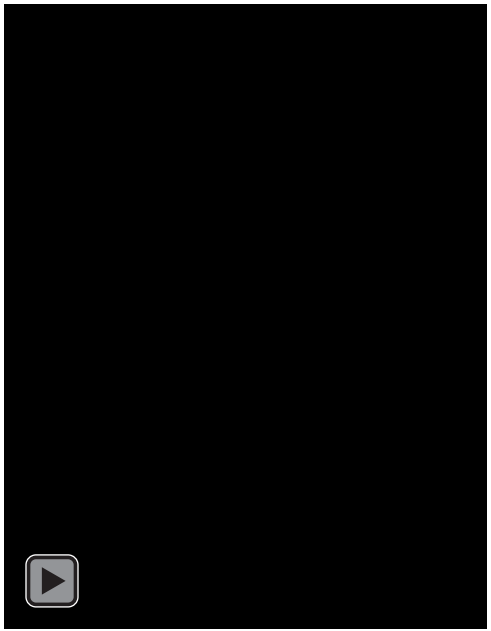


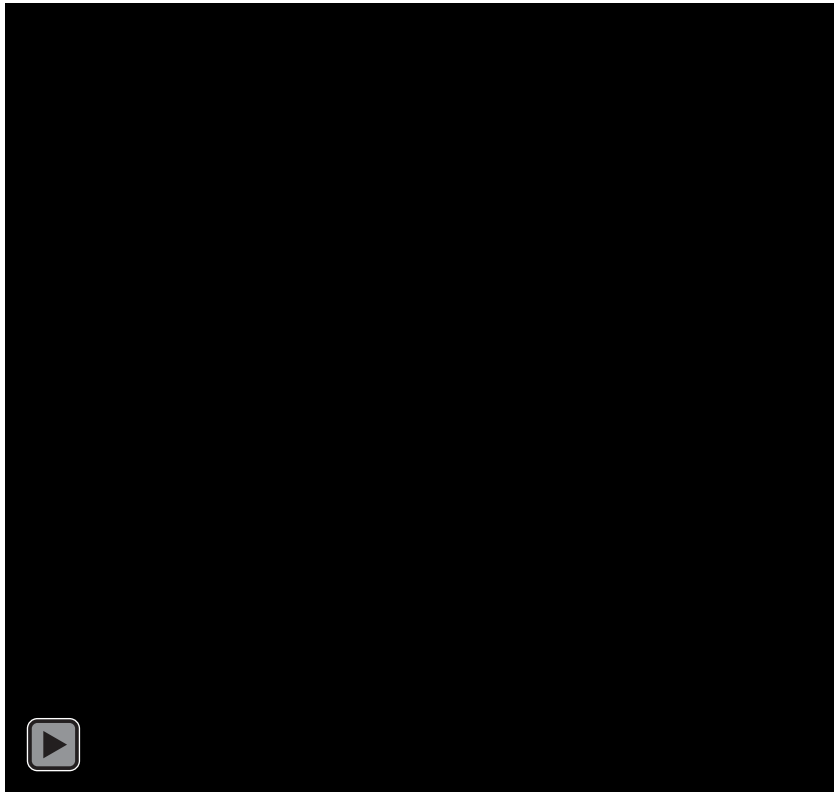
CFD Modelling – Results

Lancaster University

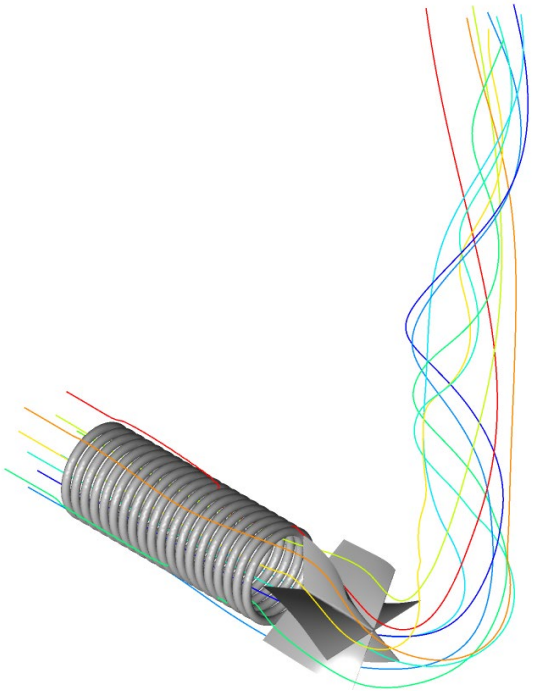
TYPHON TREATMENT SYSTEMS Ltd.

Swirl in the Cross Section

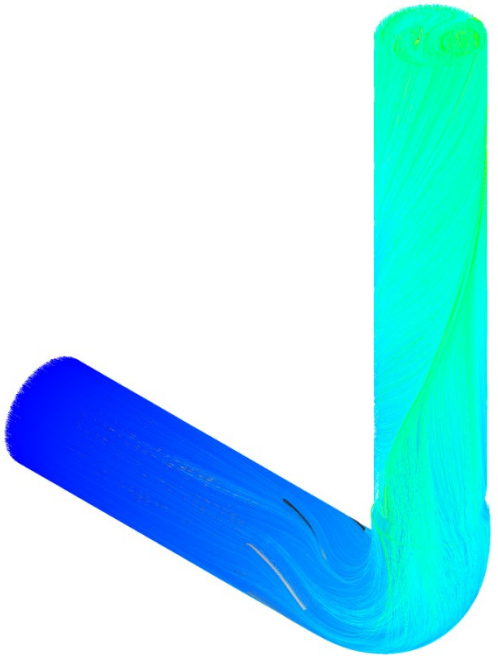




CFD Modelling – Results



10 Trajectories for Visual Analysis
(traceable by eye)

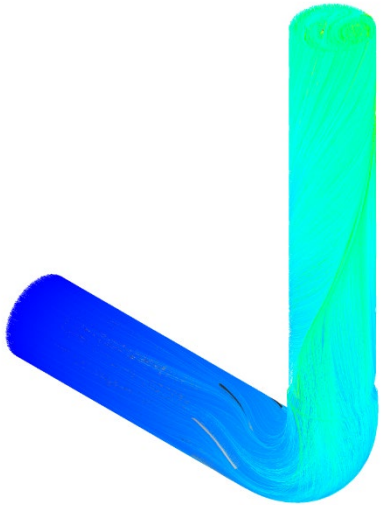


5,000 Trajectories to be Exported for
Integrated Model (untraceable by eye)

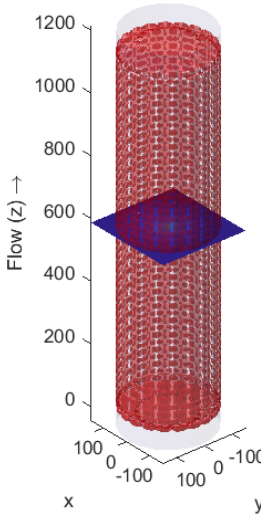
CFD Modelling – Results Integration

- **CFD Modelling Provides Trajectory Data**

  as a function of spatial location, time and velocity



+



- **Optical Modelling Provides Light Intensity Data (LID)**

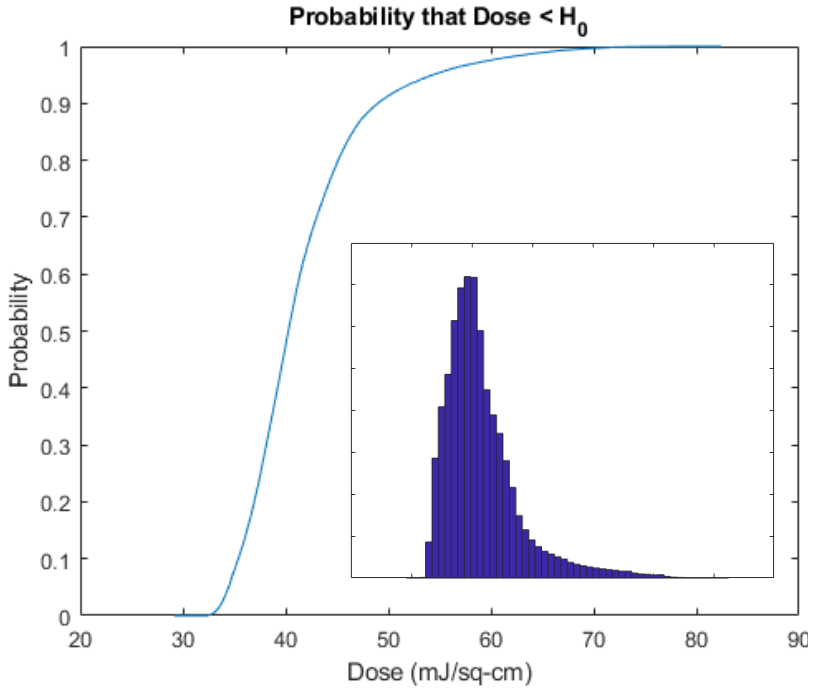
  fluence distribution in space within the reactor

Results Integration – Dose Distribution

- **A UV Dose is calculated for each trajectory:**

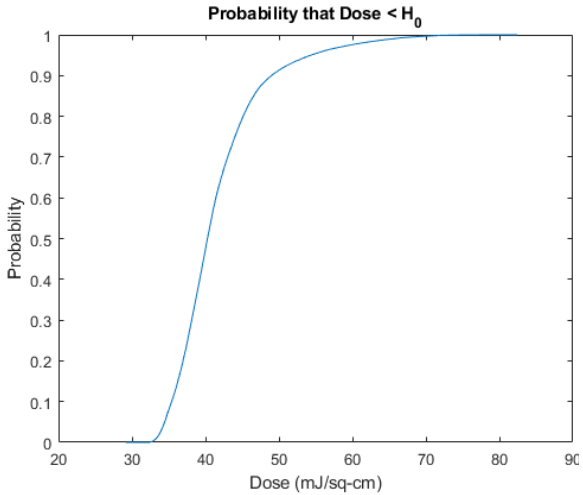
$$Dose\ of\ streamline = \sum_{i=1}^{n} Irradiance(x_i, y_i, z_i) \times \delta t_i$$

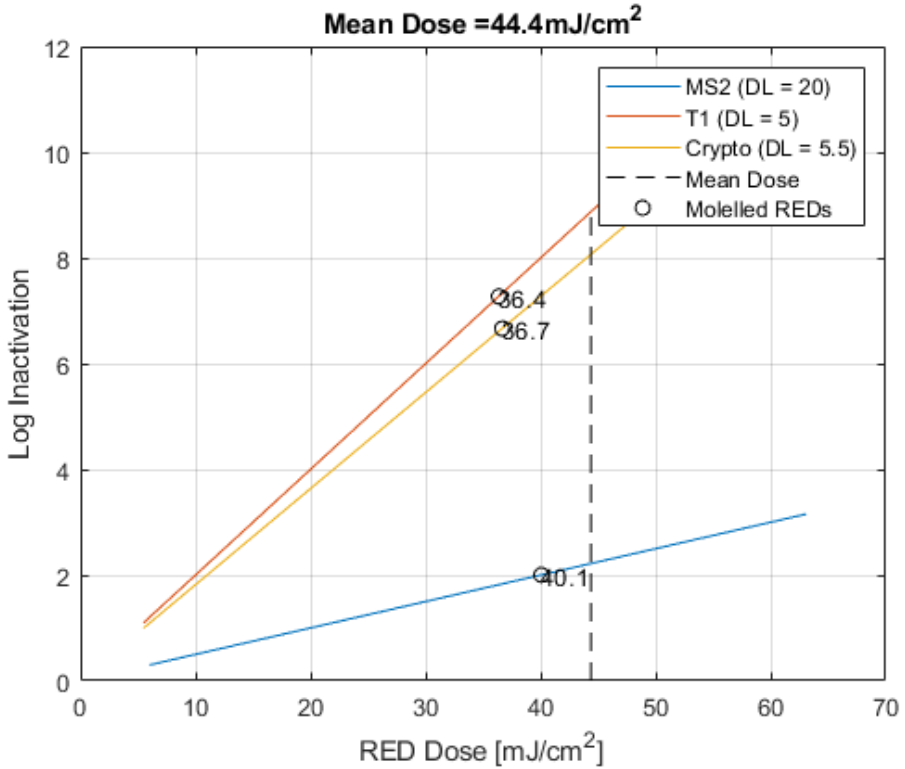
- **Dose distribution data:**



Mean Dose, Log I, RED & Efficiency

- **Convert Dose Distribution into Log I**
- **Convert Log I into RED**
- **Reactor Efficiency = RED / Mean Dose**





Reactor Efficiency

- **At General Disinfection Conditions**

  40 mJ/cm² Dose

  2 Log I MS2

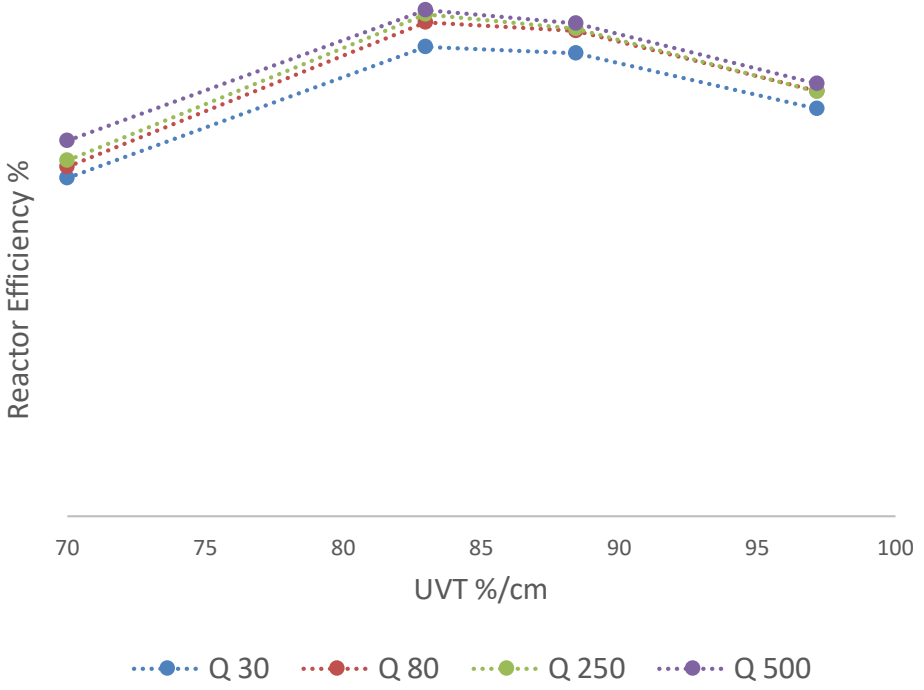
- **Consistent Efficiency over the Range of Flows**

  Q = 30 m³/h

  Q = 80 m³/h

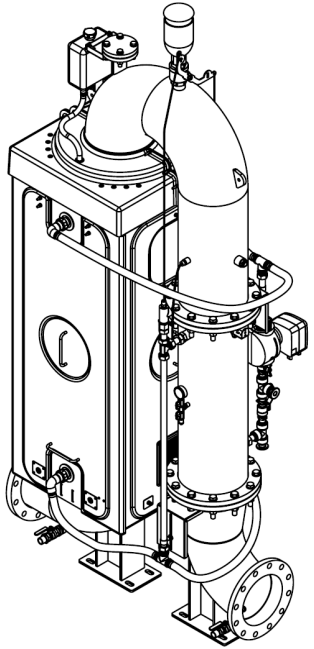
  Q = 250 m³/h

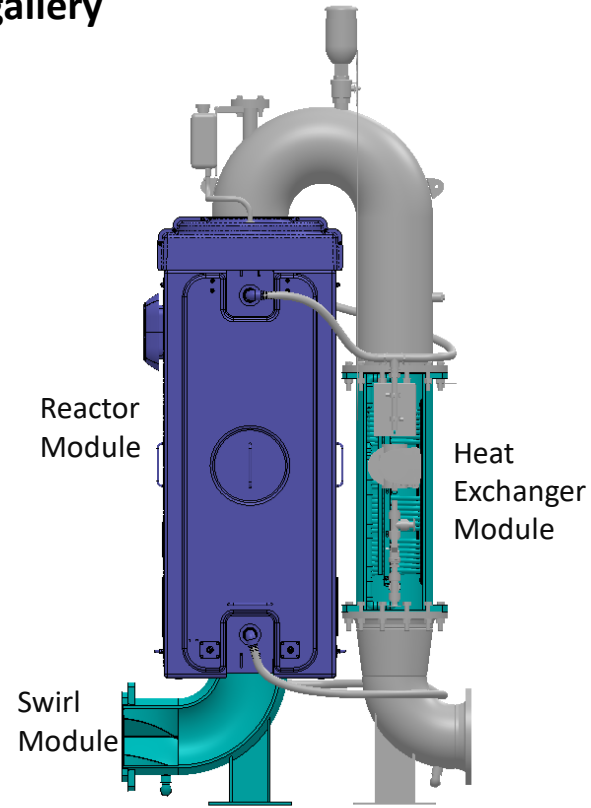
  Q = 500 m³/h



Case Study: Existing site retrofit

- **Limited space in filter gallery**
- **Modular solution**





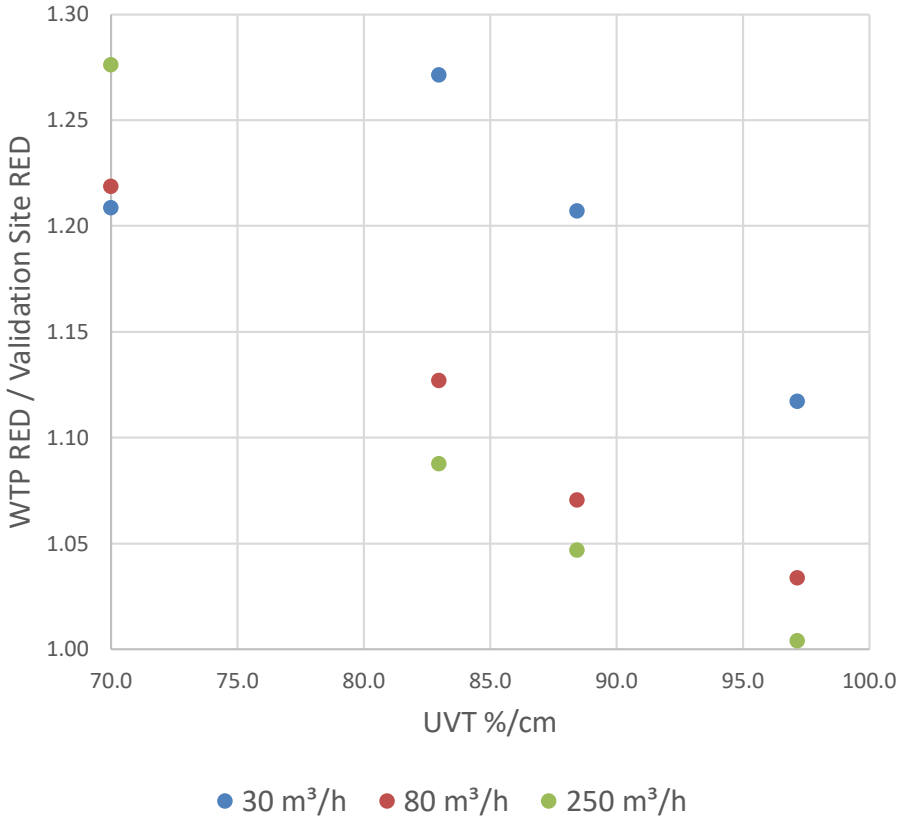
Case Study: Existing site retrofit

- **Water Treatment Plant (WTP)**

  4 log I Cryptosporidium

  Max Flow per Line 250 m³/h

- **REDs same or greater in WTP at relevant flows**

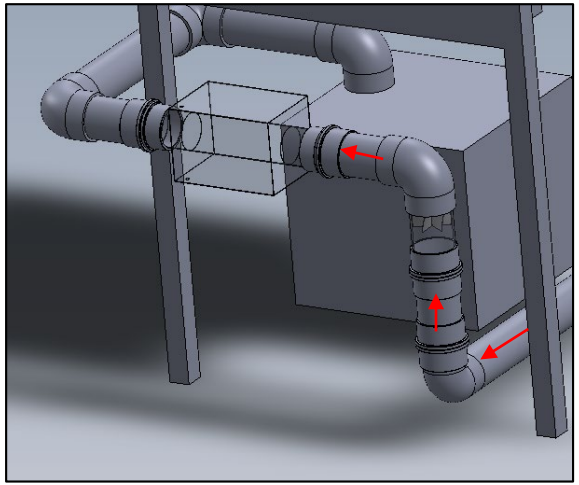


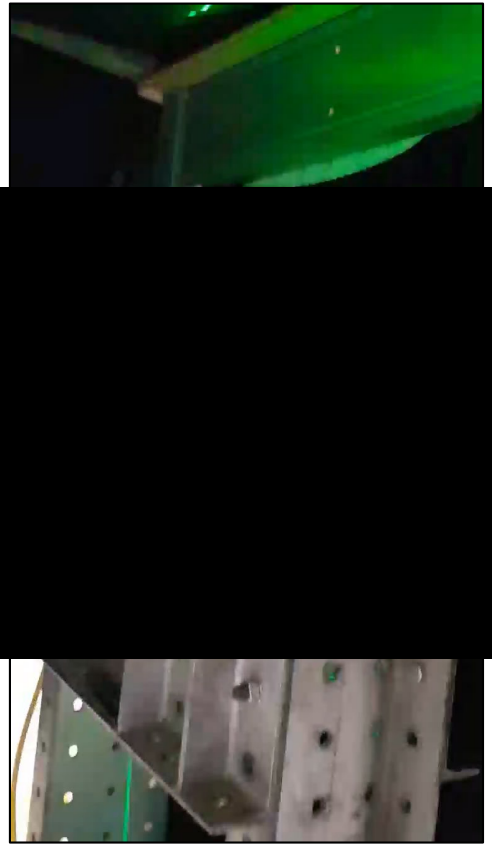
Ongoing Research

- **Additional Calibration of CFD Models**

Particle Image Velocimetry (PIV) with Pulsed Laser

Realistic Scale Large Diameter Pipework

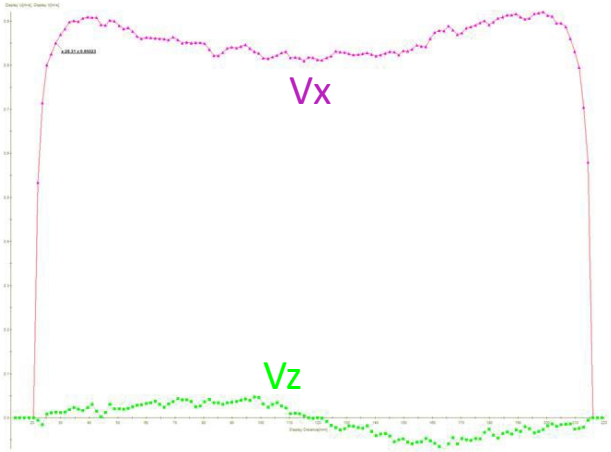


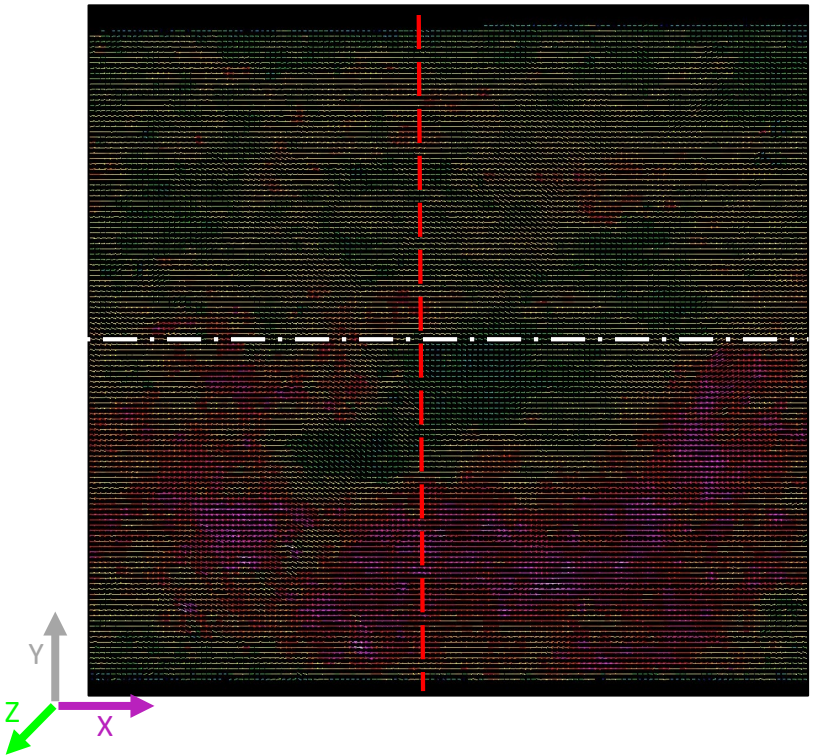


Ongoing Research

- **Additional Calibration of CFD Models**

Velocity vectors measured vs CFD





Summary

Conclusions

Municipal Scale UV LED Reactors are Available Today

Multiple LED/Reflector Pairs Provide Unique Challenges in Reactor Modelling

New Methodology Introduced and Presented

Reactor Performance Optimized by Modelling

Modelling was used to Aid Validation Process

Case Study for Modular Retrofit Installation

Next Steps

Model Assessment vs Experimental Results

Calibrate the Model to Experimental data