

ICARST 2017

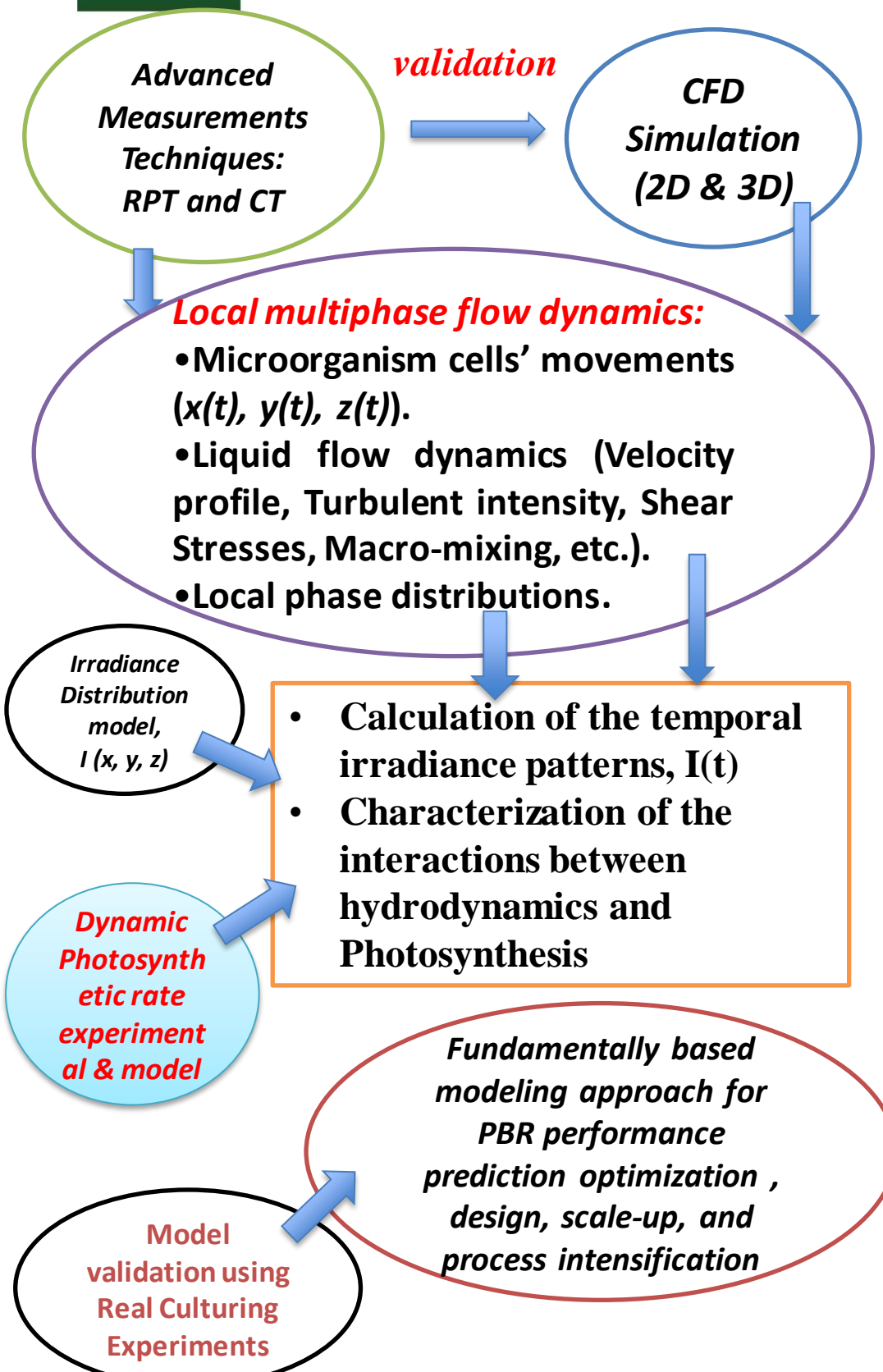
1st International Conference on Applications
of Radiation Science and Technology

Radioactive Particle Tracking (RPT) Technique for Tracking Microalgae's cells Movement Velocity Field in a Split photobioreactor Column

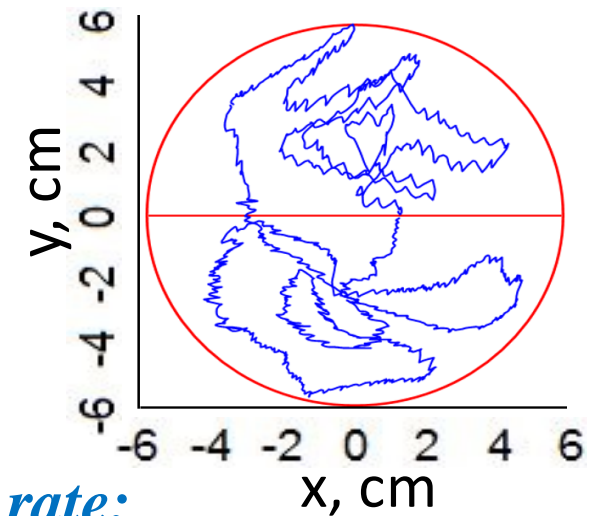
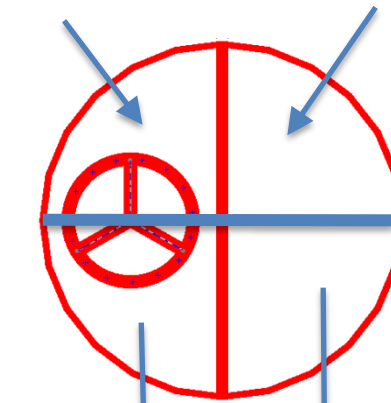
Laith S. Sabri, Abbas J. Sultan, Muthanna H. Al-Dahhan[†]

[†]Multiphase Reactors Engineering and Applications Laboratory (mReal)

[†] *Department of Chemical and Biochemical Engineering, Missouri University of Science and
Technology, Rolla, MO 65409-1230. USA*



Riser Downcomer



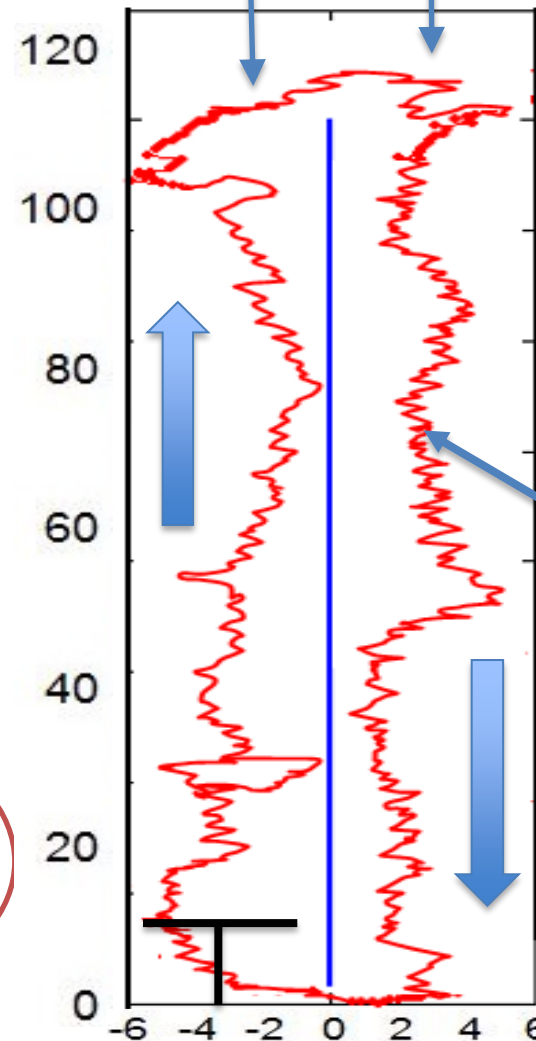
Growth rate:

$$\frac{1}{x} \frac{dx}{dt} = \mu = k \cdot \gamma \cdot x_2 - Me$$

The numerical solution for all Differential equations above find x_1 , x_2 and x_3 , and sub. in below:

$$I(t) = I_0 \cdot \exp \left\{ \begin{array}{l} -(k_x \cdot x^j + k_w) \\ \times \left[d^j + \frac{t-t^j}{t^{j+1}-t^j} (d^{j+1} - d^j) \right] \end{array} \right\}$$

$$t^j < t < t^{j+1}$$

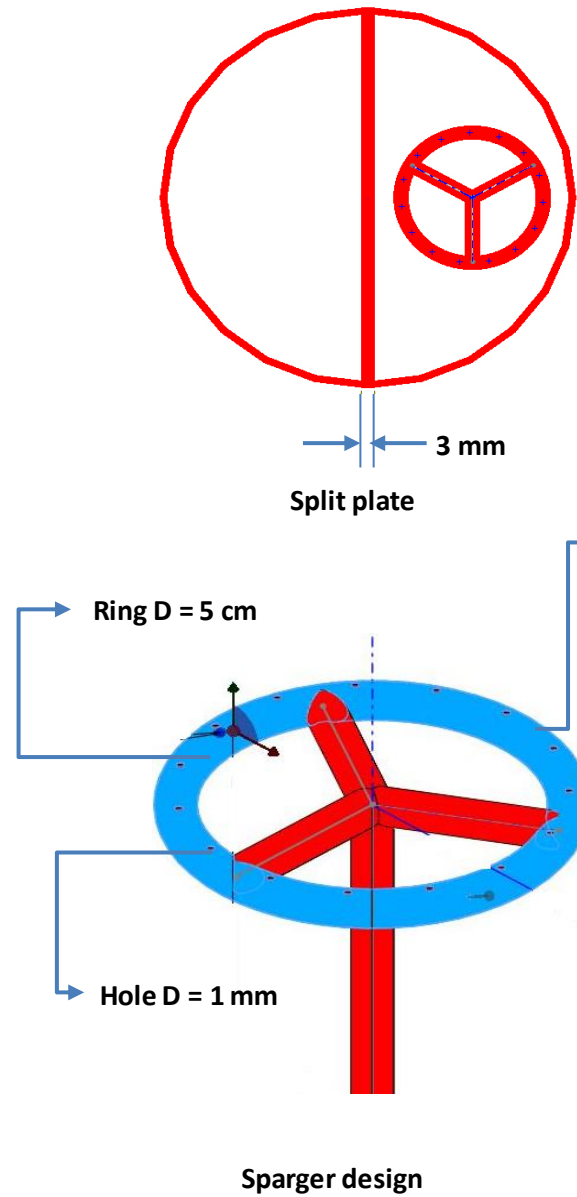
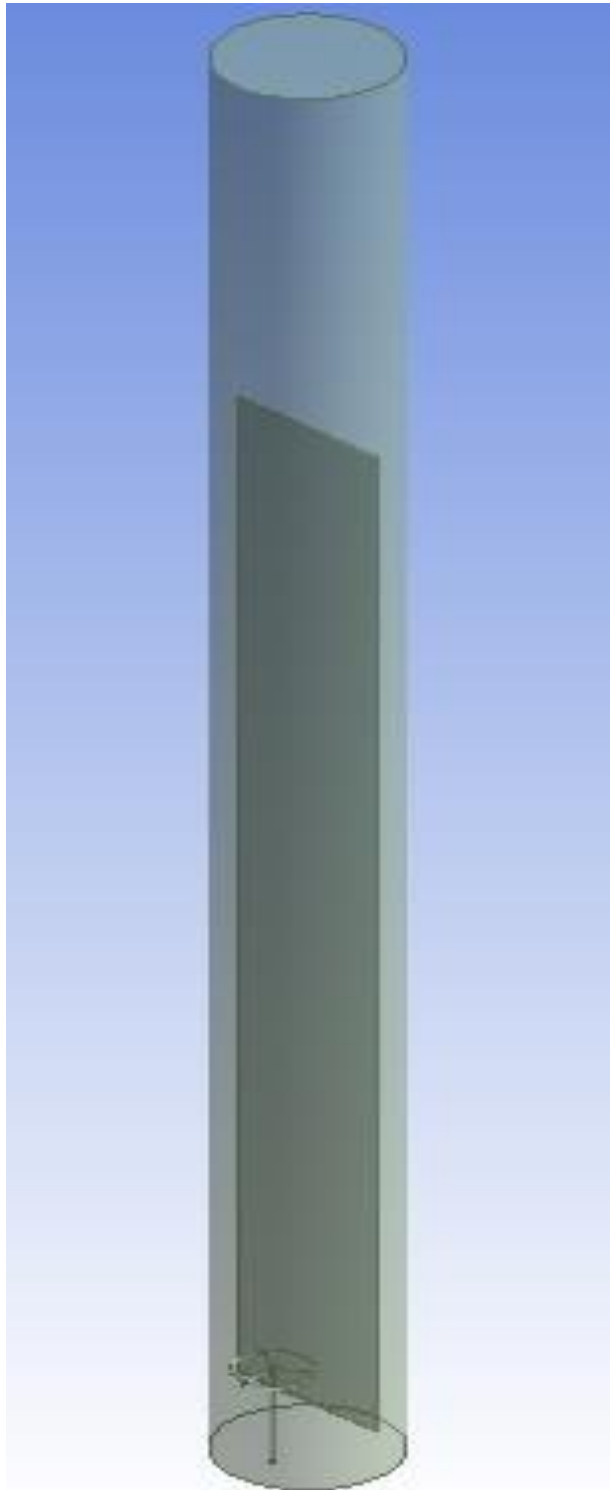


Instantaneous irradiance light History: $I = f(t, \text{cell positions})$. Calculated by using Lambert-Beer law and RPT measured trajectories to provide $(I(t), x, y, z)$.

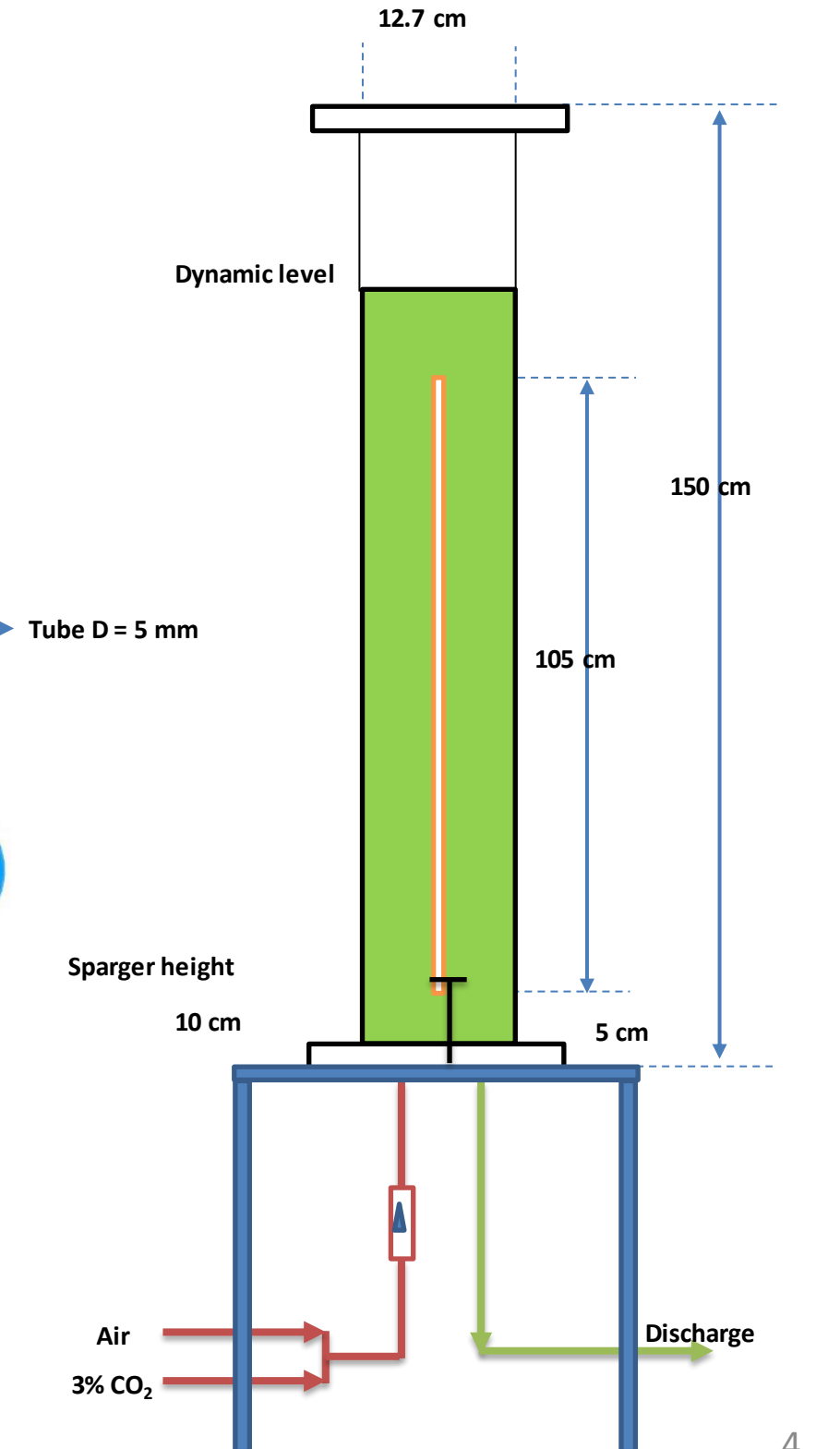
Introduction & Motivation

- Microalgae are fast growing photosynthetic organisms. The yield of microalgae biomass is many times superior to that of higher plants due to their shorter life cycle and their efficient growth.
- Microalgae culturing is not well understood due to complex hydrodynamics and their complex interaction with light due to lack of implementing of advanced measurement techniques.
- Cells movement determines the cells fluctuation and their residence time in the light and dark zones which has not measured and determined during microalgae culturing.
- Therefore, this work focuses on studying for the first time the cells movement (trajectory) and their local velocity field in split airlift photobioreactor, by using advanced hydrodynamics measurement techniques, namely RPT (Radioactive Particle Tracking).
- This knowledge is essential for implementing our advanced approach in predicting the performance and optimizing the microalgae culturing which enable proper, cost effect design, scale up and identifying the proper type of photobioreactor whether open or close type.





Schematic diagram for the used split airlift bioreactor with the ring sparger

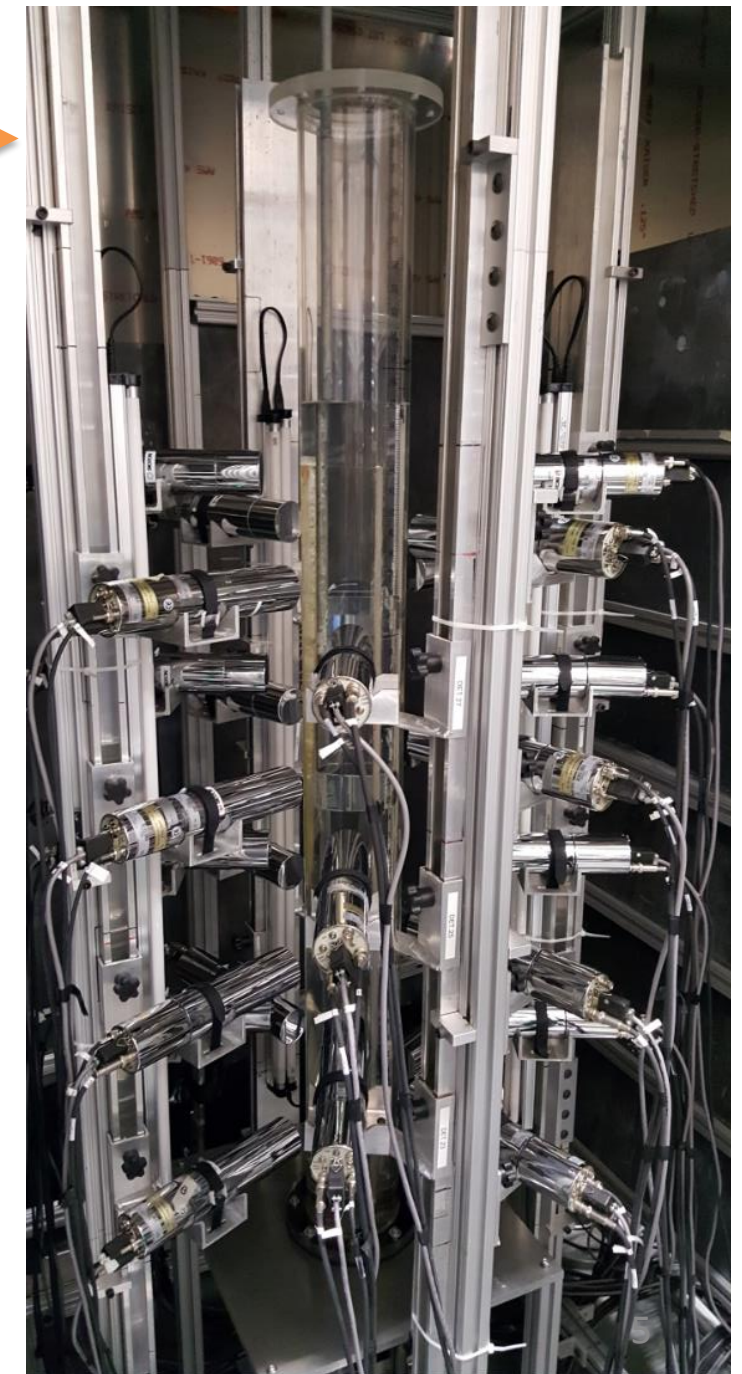


Radioactive Particle Tracking (RPT) Technique

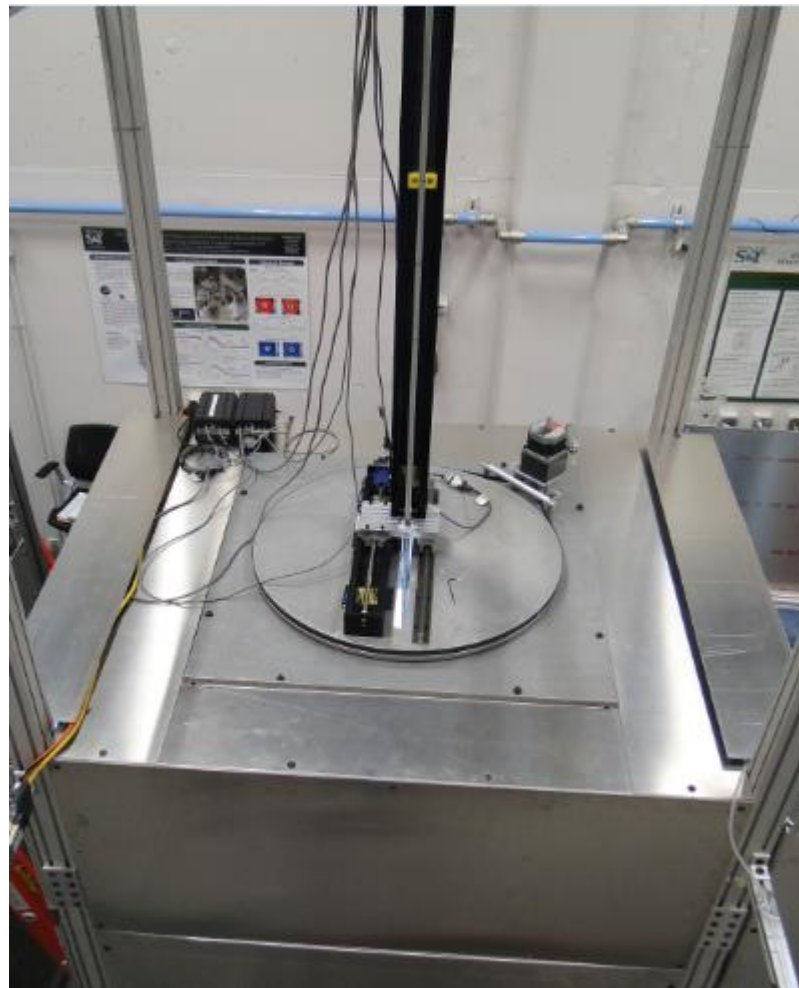
Electronics and Data acquisition system

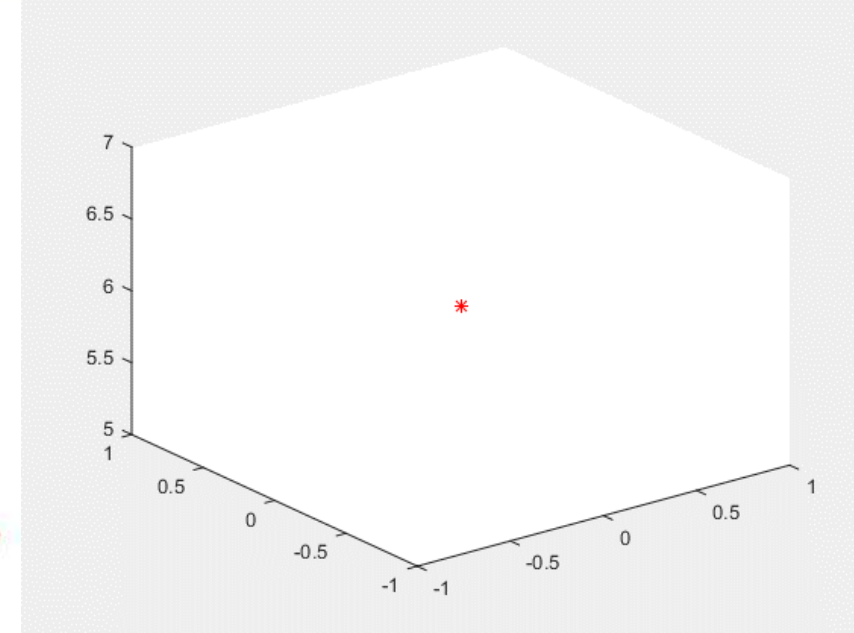
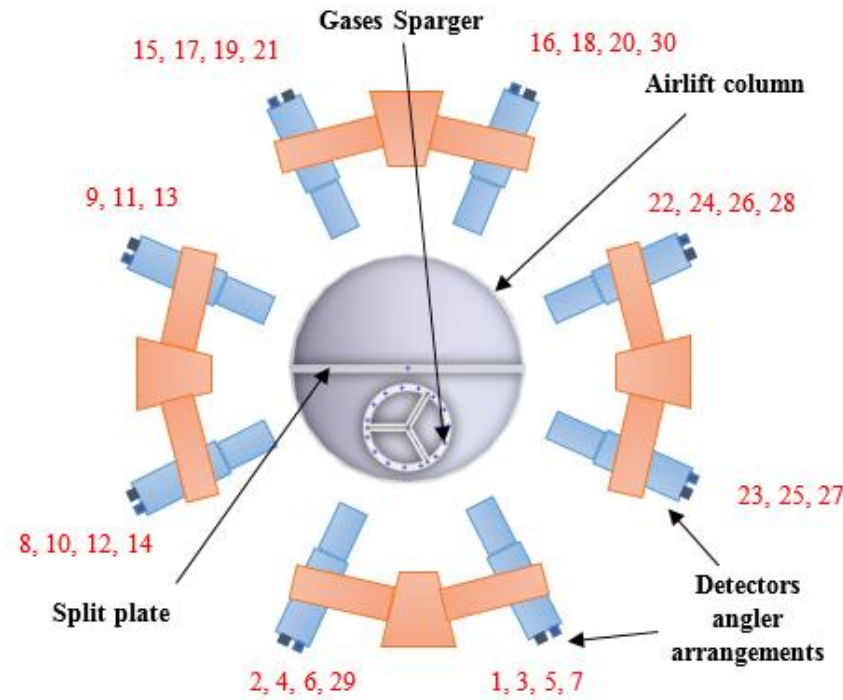
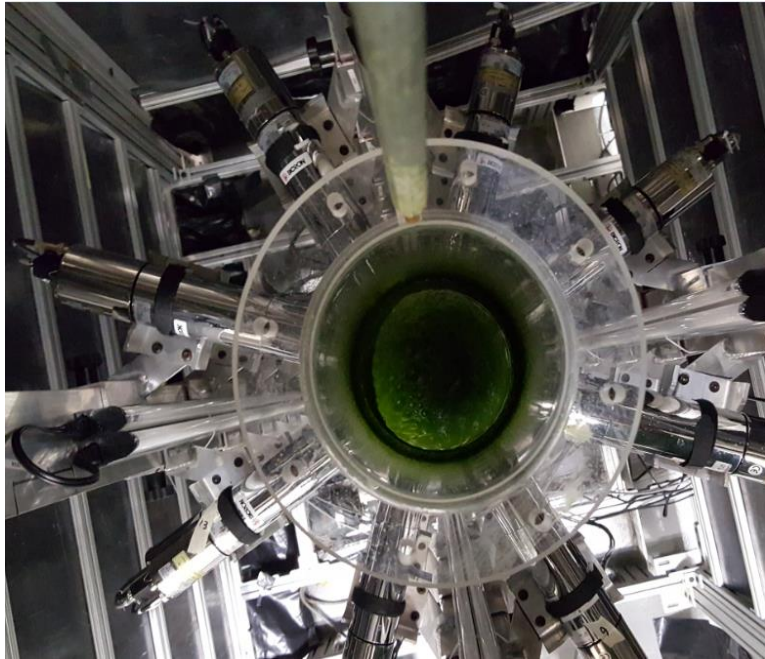


30 NaI Detector

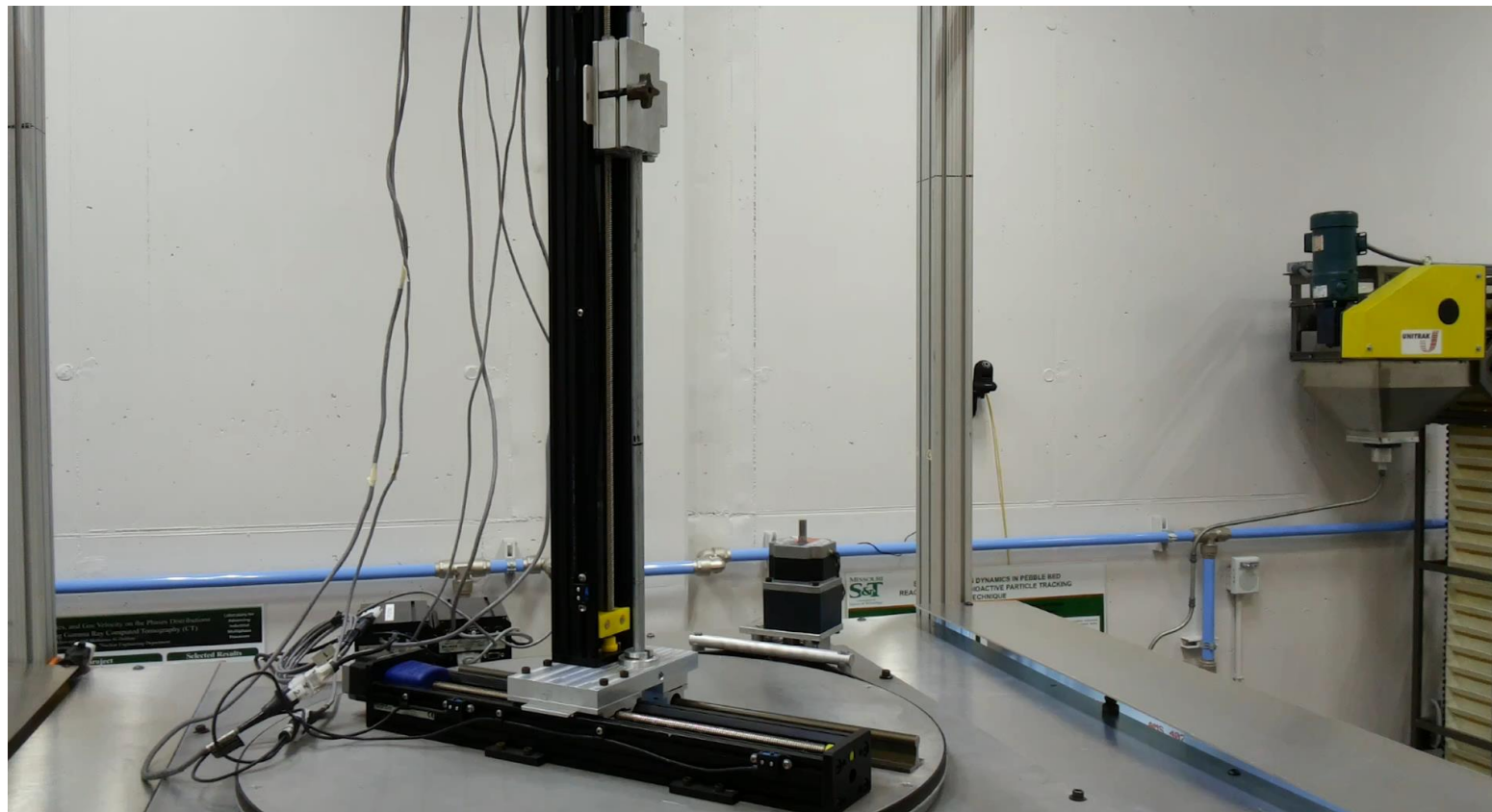


Fully Automated calibration device

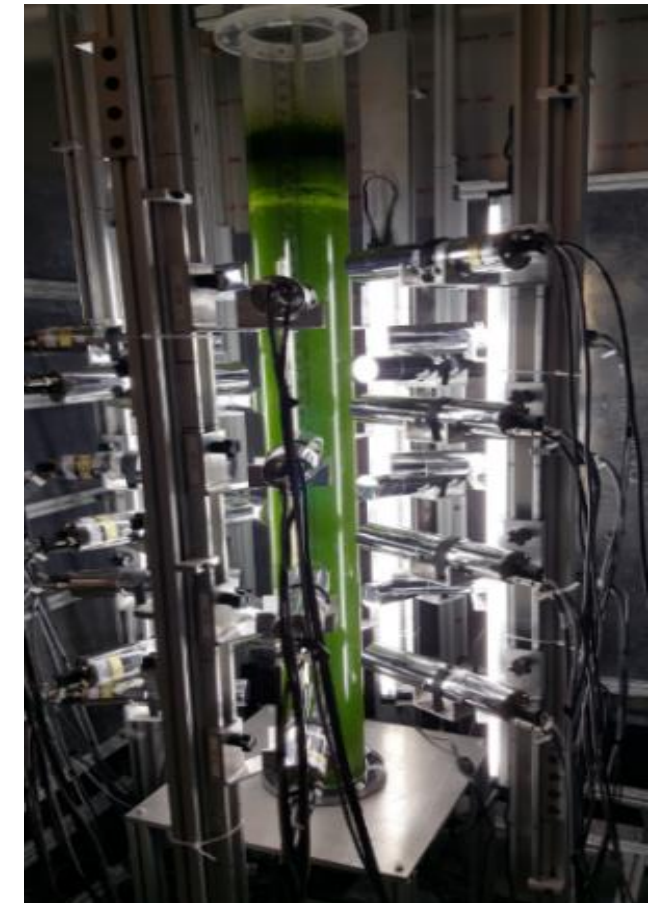




Video shows the 3D calibration points build



Video shows the 3D slides moving for calibration device



Configuration of the setup

Unknown empty space to adjust the neutrally

Mix epoxy glow

1.0 mm depth Hole

0.61 mm I.D. Hole

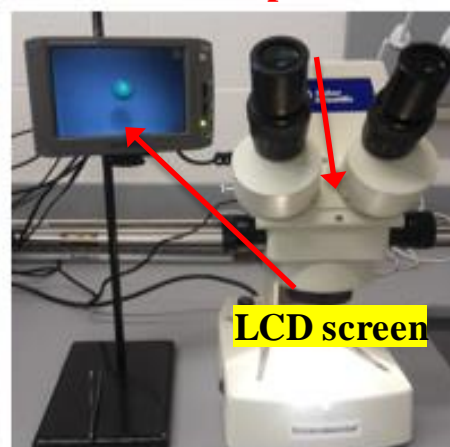
600 μ m O.D. isotopes Cobalt⁶⁰

2.0 mm D

Capsulated of Isotope Particles to make it similar to the density of cells/liquid density

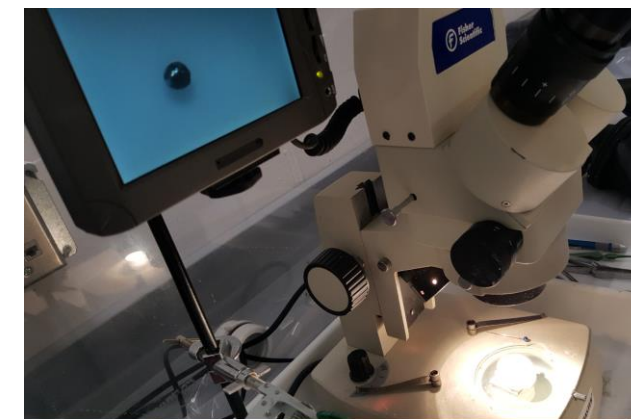
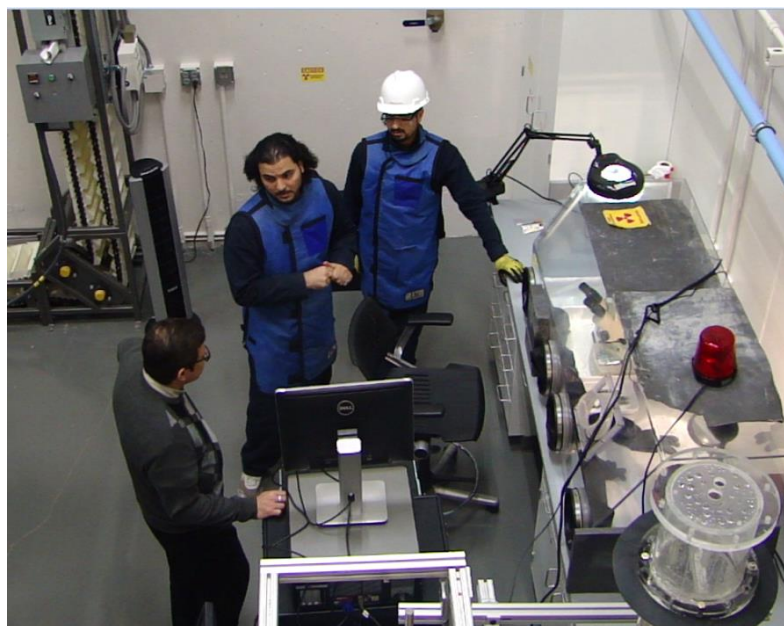
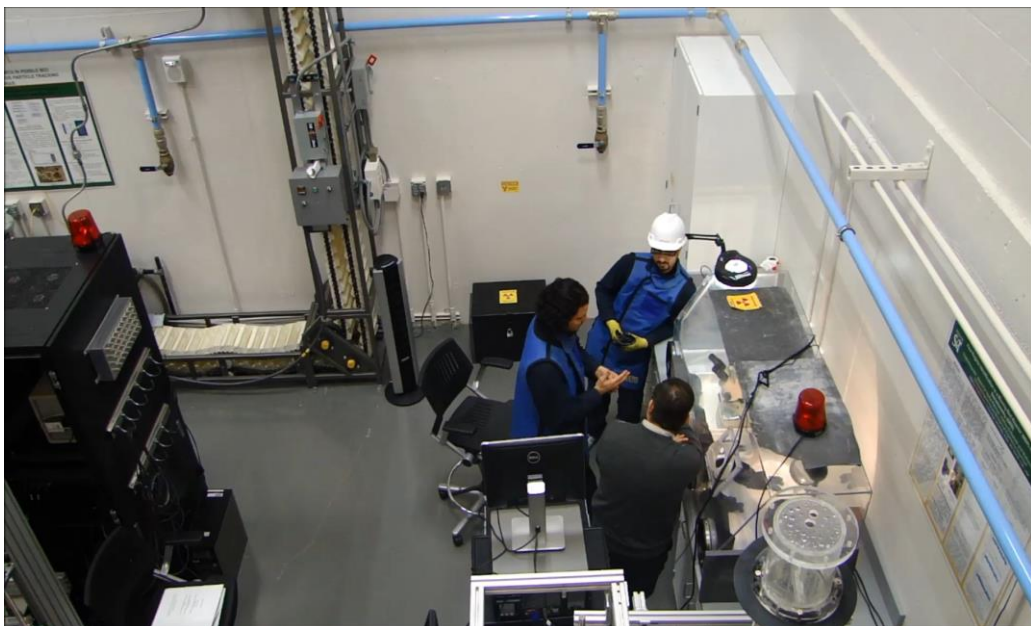
Glove Box for particle preparation

Microscope



Movie show a really capsulated experimental work of isotopes Cobalt⁶⁰ by Polypropylene particle under Environmental Dep. Screening

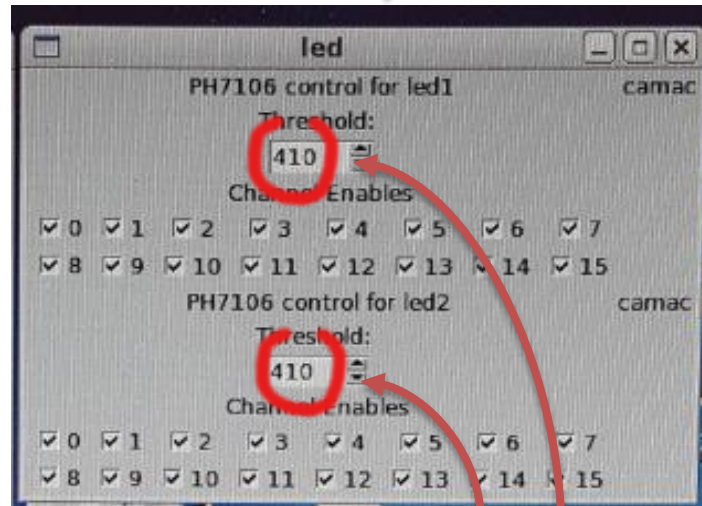
Movie (slow-motion) show how the tracer particle is neutrally buoyance with liquid/cells.



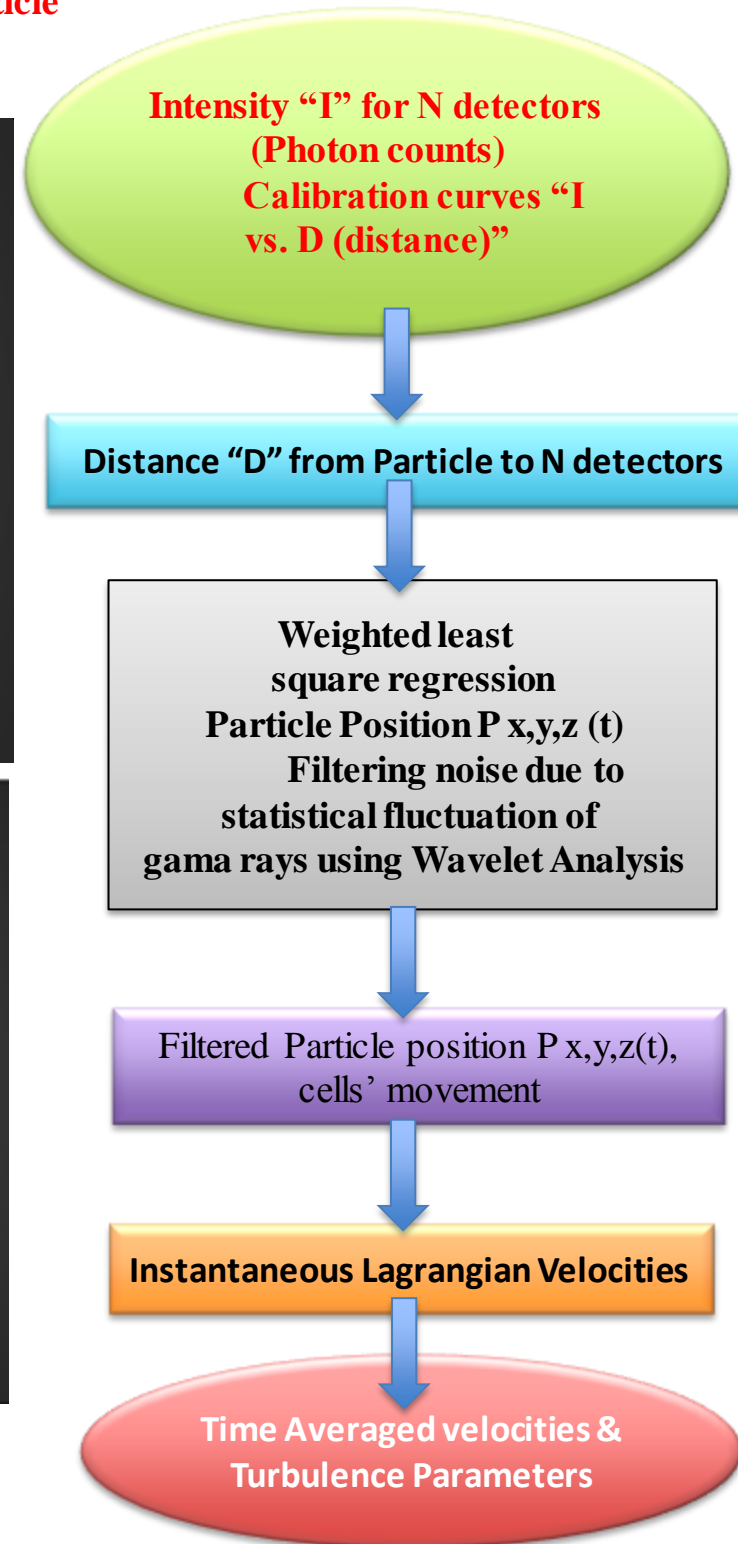
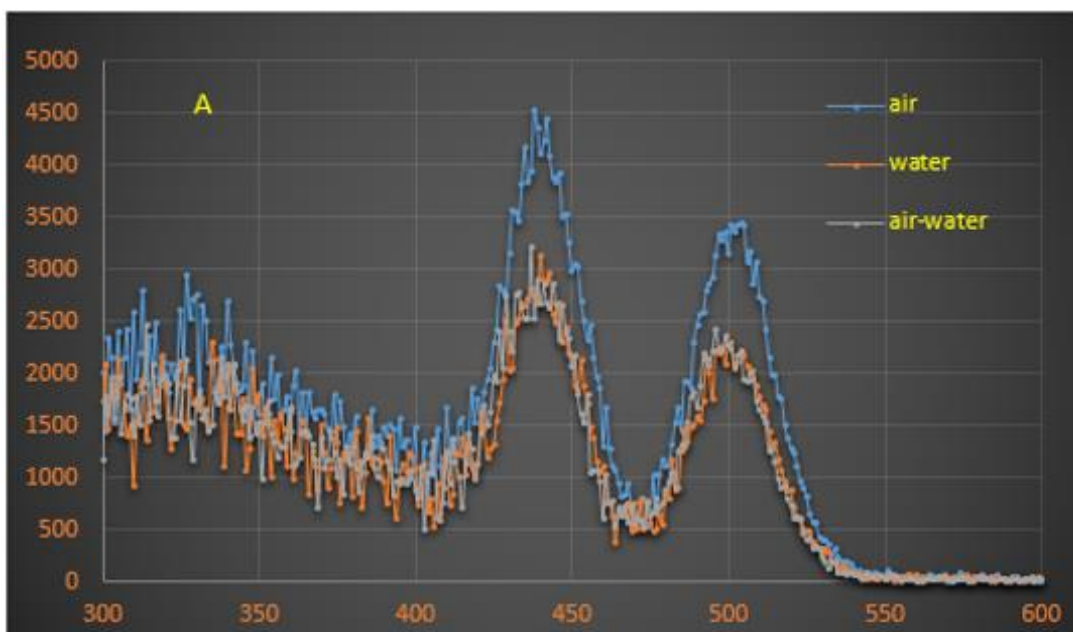
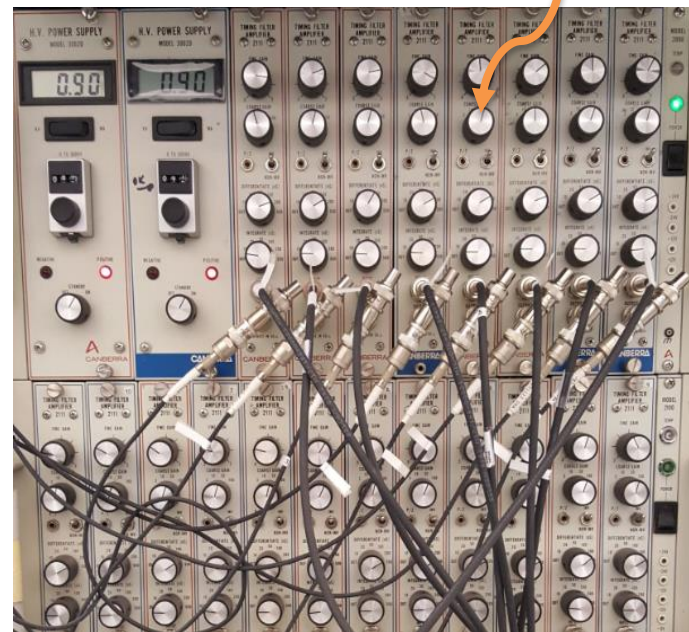
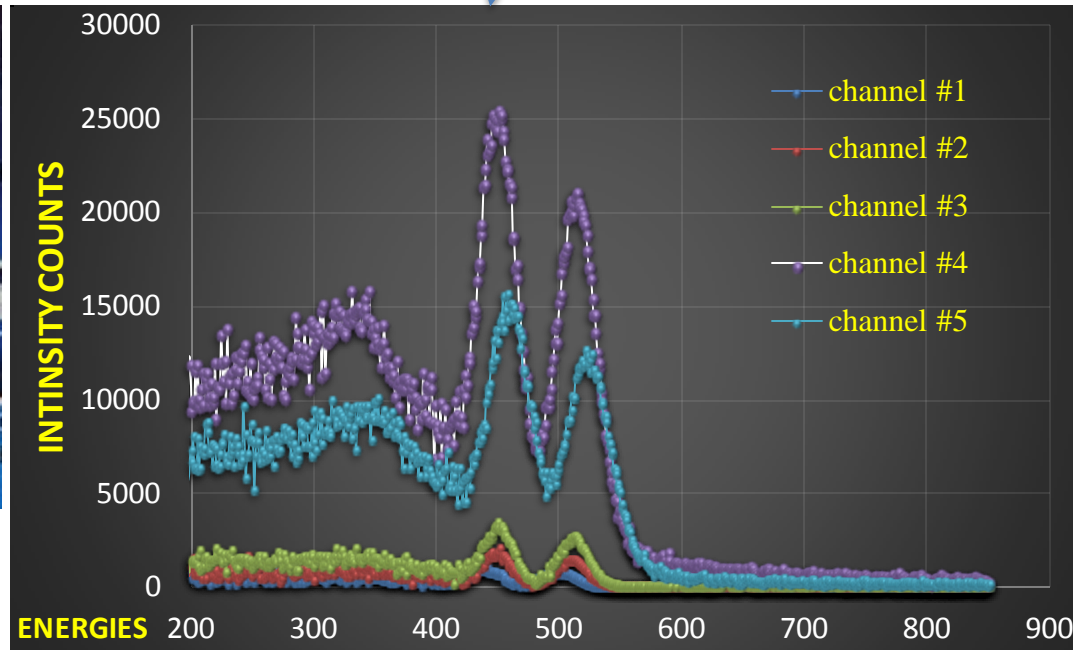
A really 600 μ m O.D. isotopes Cobalt⁶⁰

Determined Multichannel Analyzer (MCA)

Data Processing of Radiation Intensity Received by N Detectors from a Single Radioactive Cobalt60 Particle



Feed the RPT software, the value of the MCA to avoid the scattering signals, by using bellow:



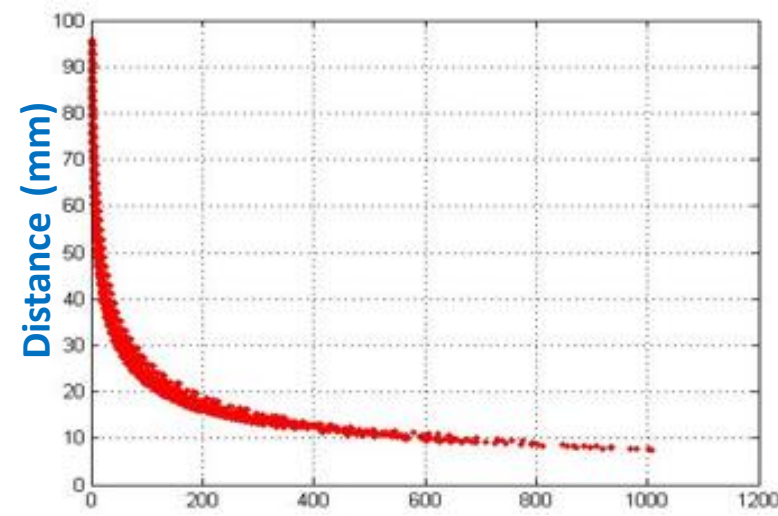
Experimentally determined energy spectrums for different medium and velocities

Calibration analysis for different cells growing stages and the Reconstruction Error

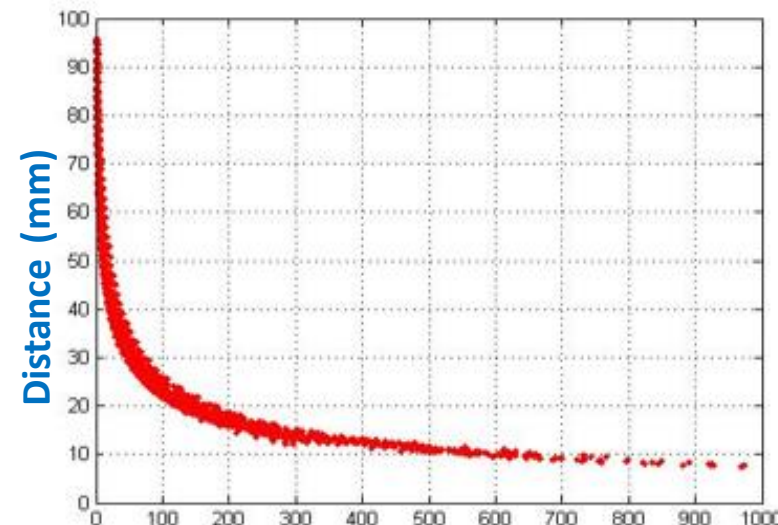
The reconstruction error and its projection on the radial direction can be calculated from (H.-P. Luo 2005) **Reconstruction Error based on Calibration (time-averaged, free of white noise):**

$$\text{Reconstruction error (x, y, z - domain)} = \frac{\sum \sqrt{(x_{real} - x_{rec})^2 + (y_{real} - y_{rec})^2 + (z_{real} - z_{rec})^2}}{N}$$

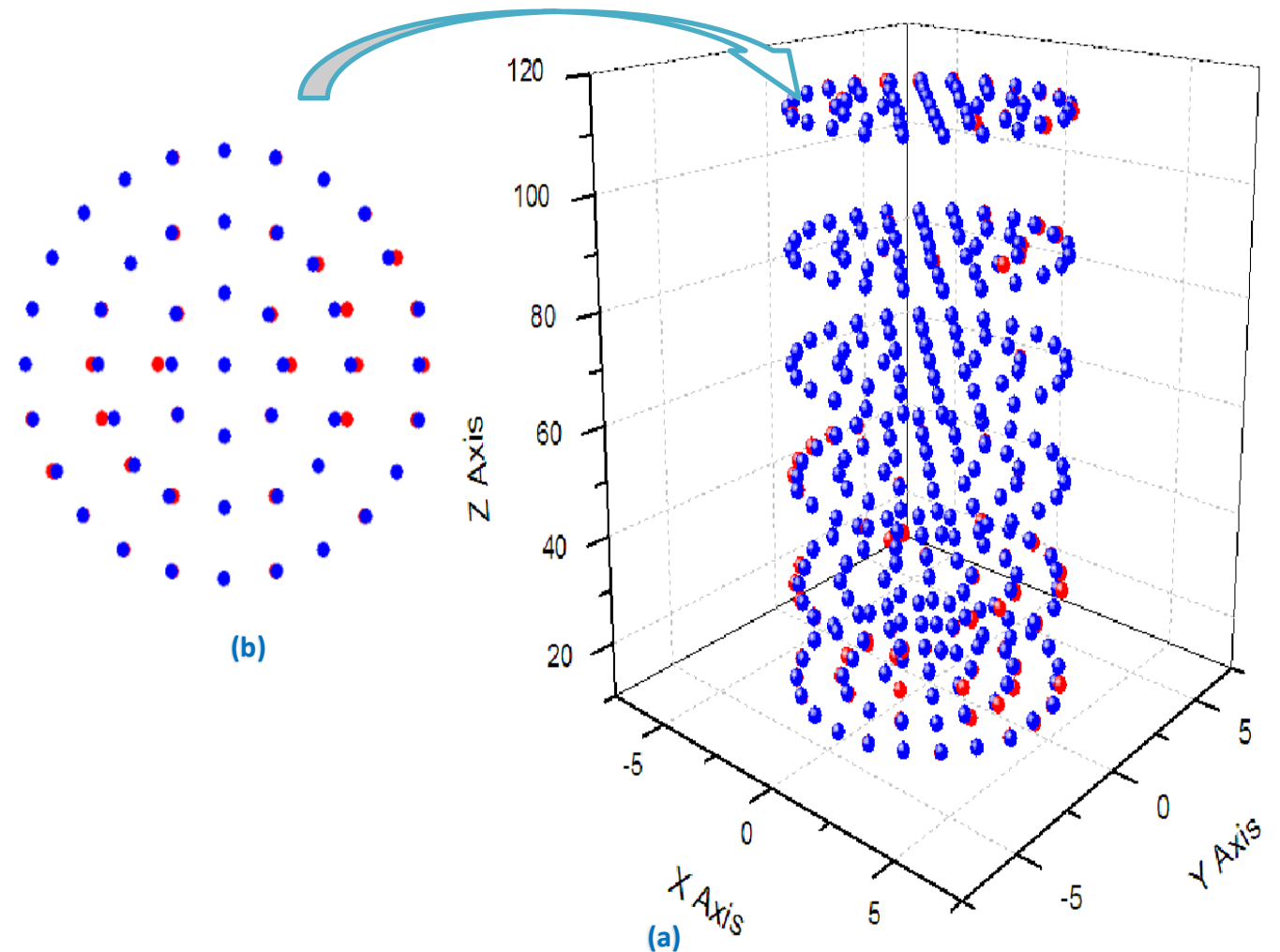
$$\text{Reconstruction error (radial domain)} = \frac{\sum \sqrt{(x_{real} - x_{rec})^2 + (y_{real} - y_{rec})^2}}{N}$$



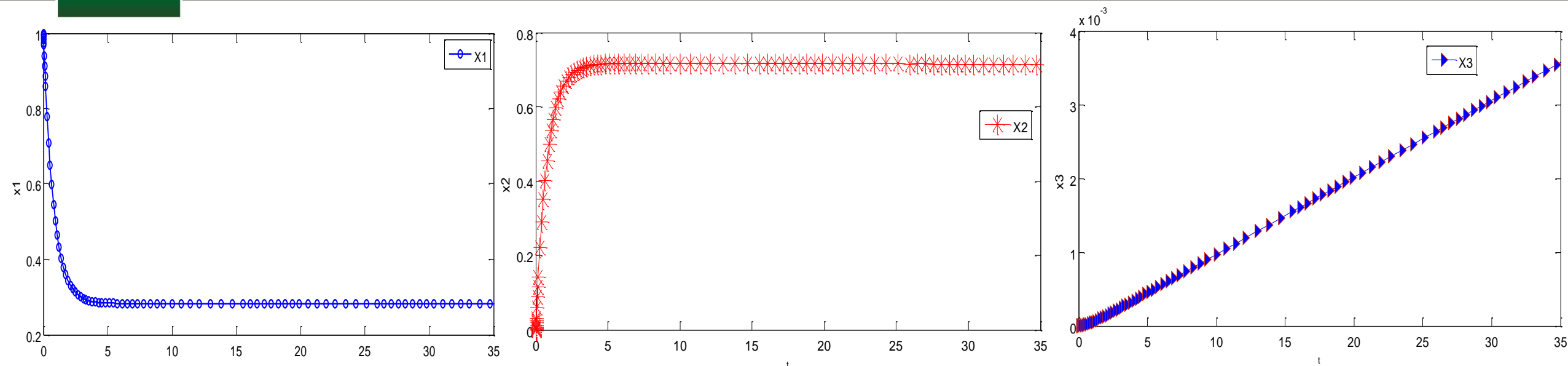
Optical Density (0.15)



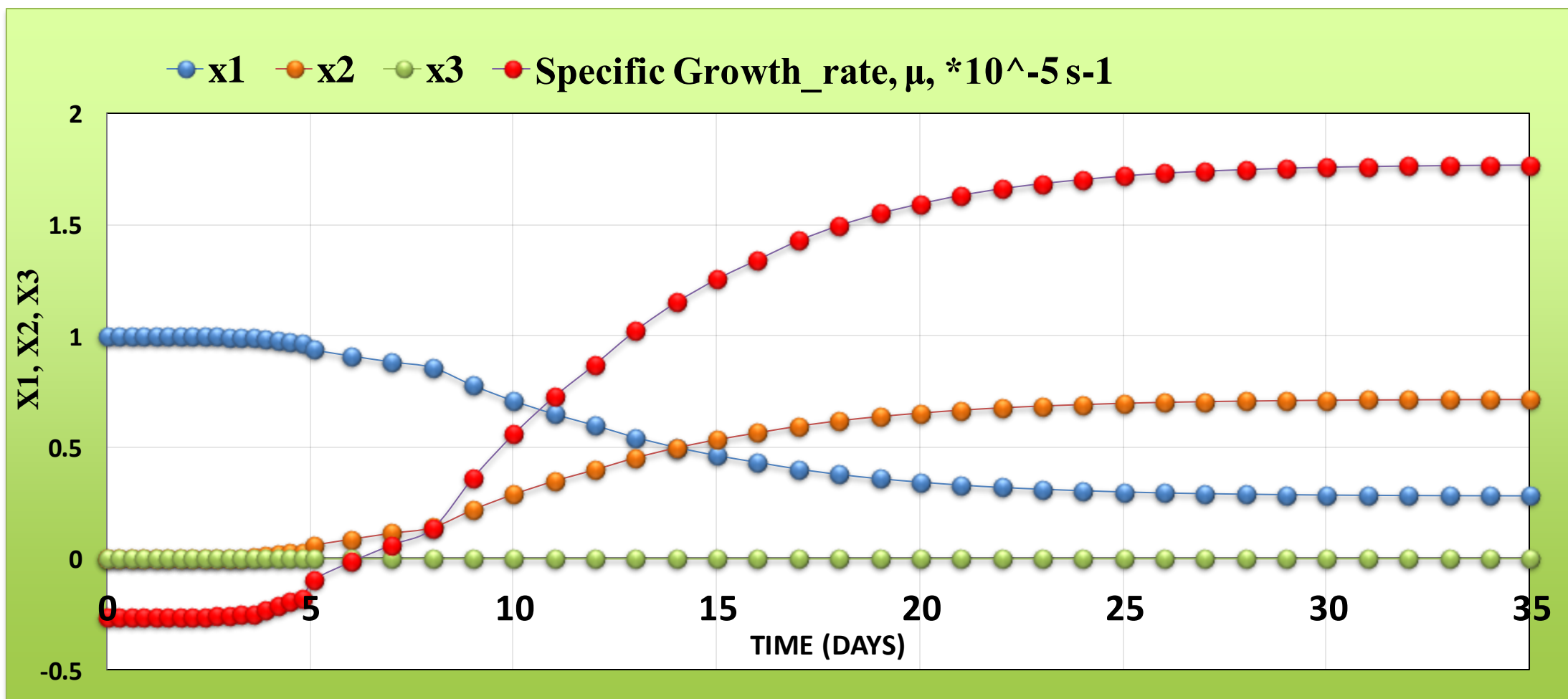
Optical Density (1.49)



Comparisons between the reconstructed positions and the real particle positions in a calibration. (a) Particle positions on the x-y-z plane; (b) Particle positions on the cross-sectional plane.

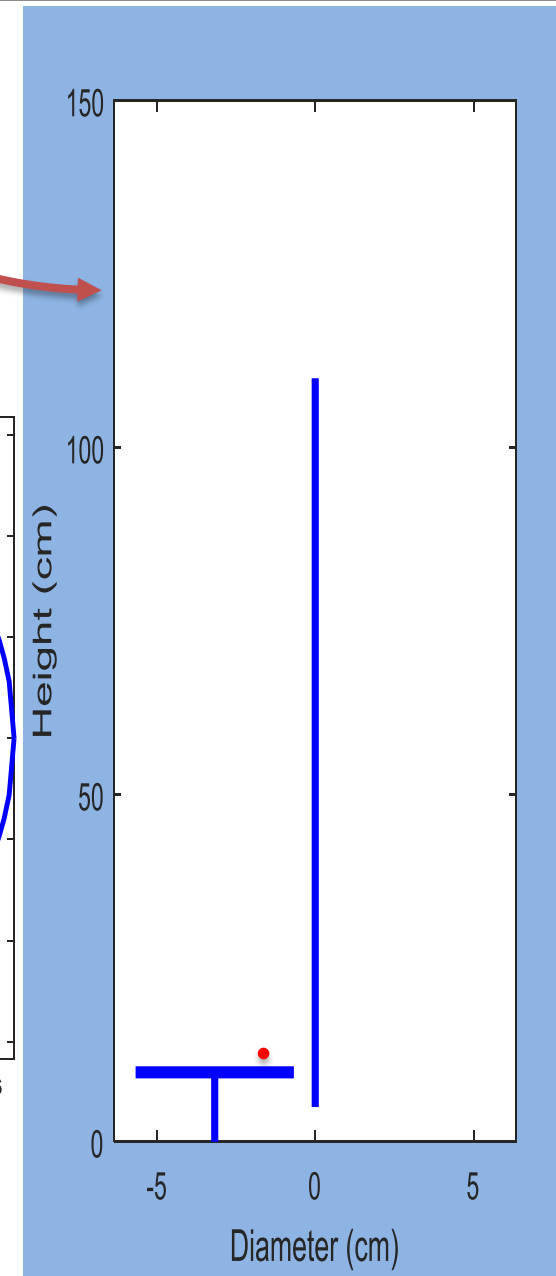
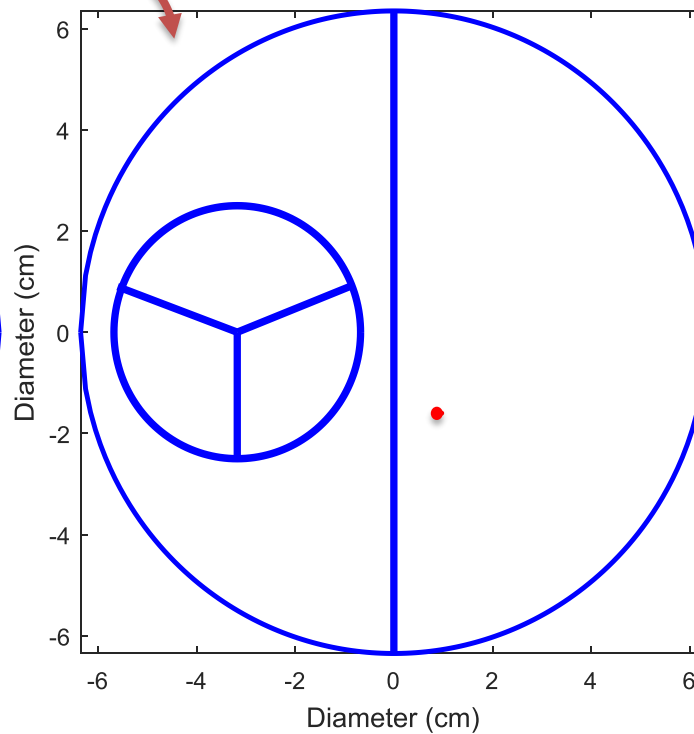
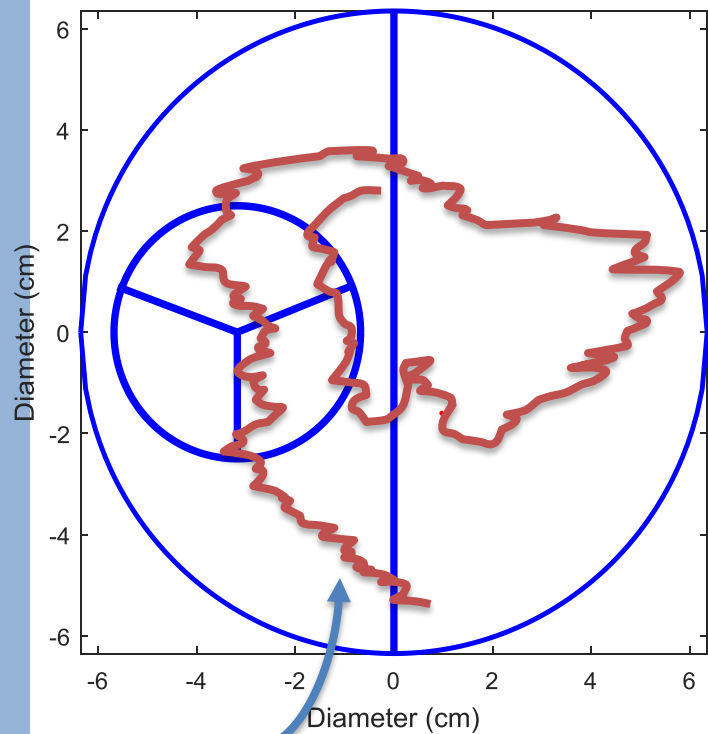
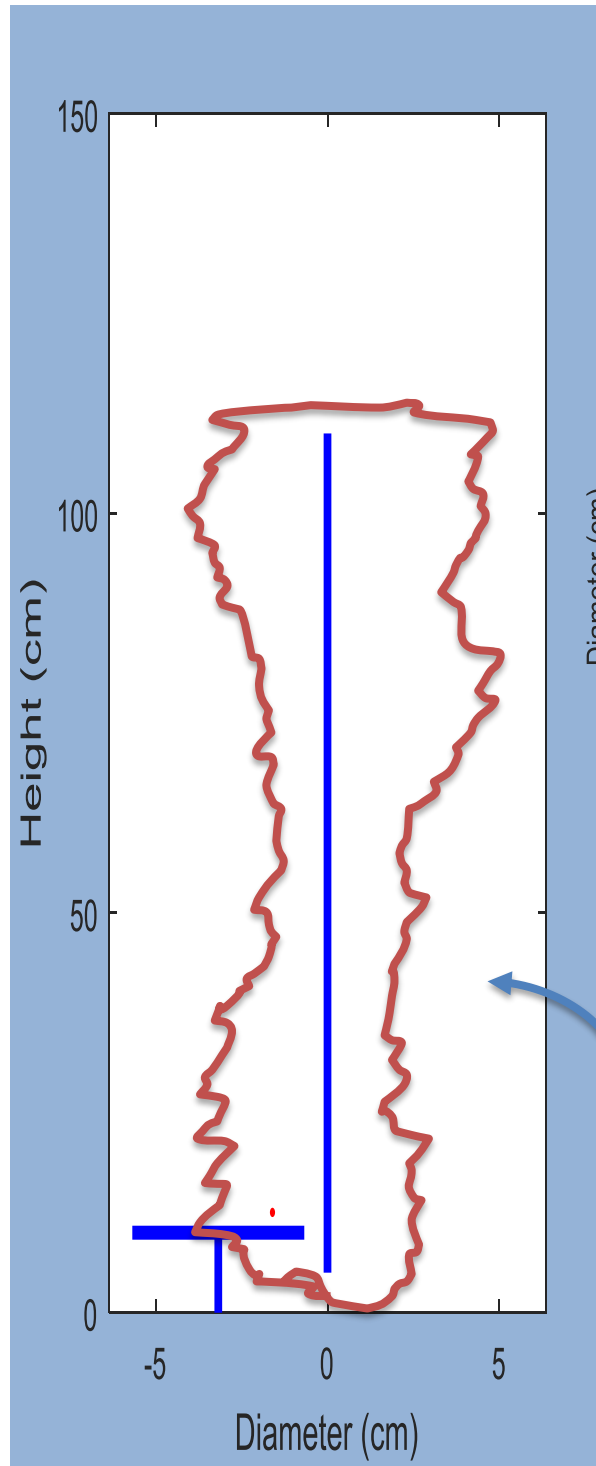


P-I curve (predicted by the analytical solution of the dynamic model), Employ 5th order R-K method to solve this IVP, Model parameters obtained for Green algae, *Scenedesmus sp*



■ Photobioreactor Analysis (*Light History*):

Isotopes particle animations

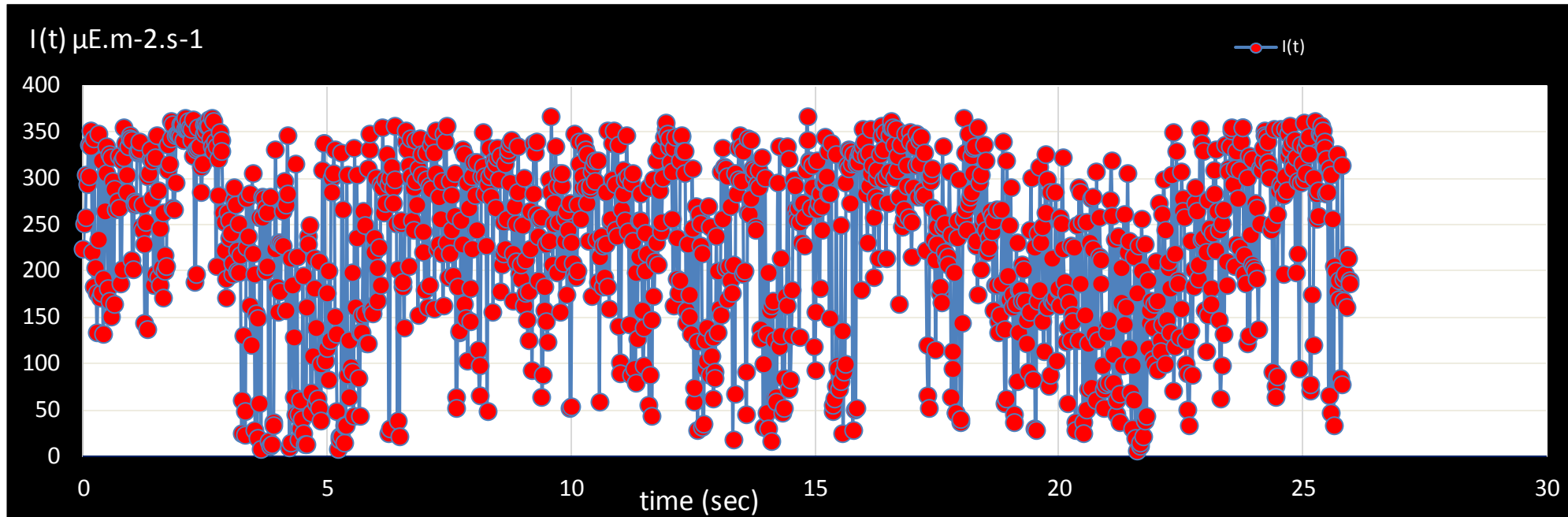


$$I(t) = I_0 \cdot \exp \left\{ - (k_x \cdot x^j + k_w) \cdot \left[d^j + \frac{t - t^j}{t^{j+1} - t^j} (d^{j+1} - d^j) \right] \right\}$$

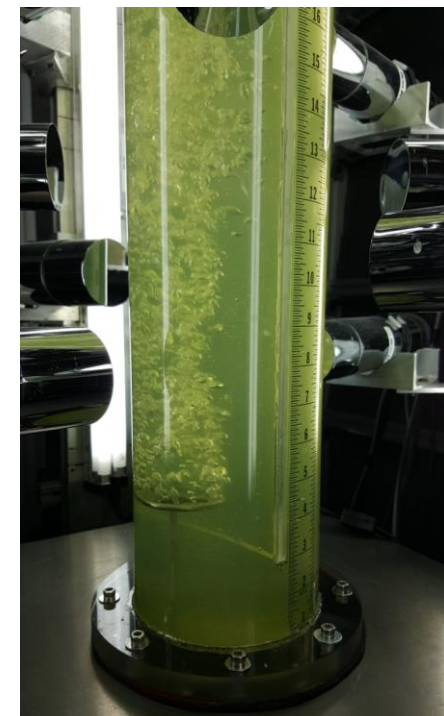
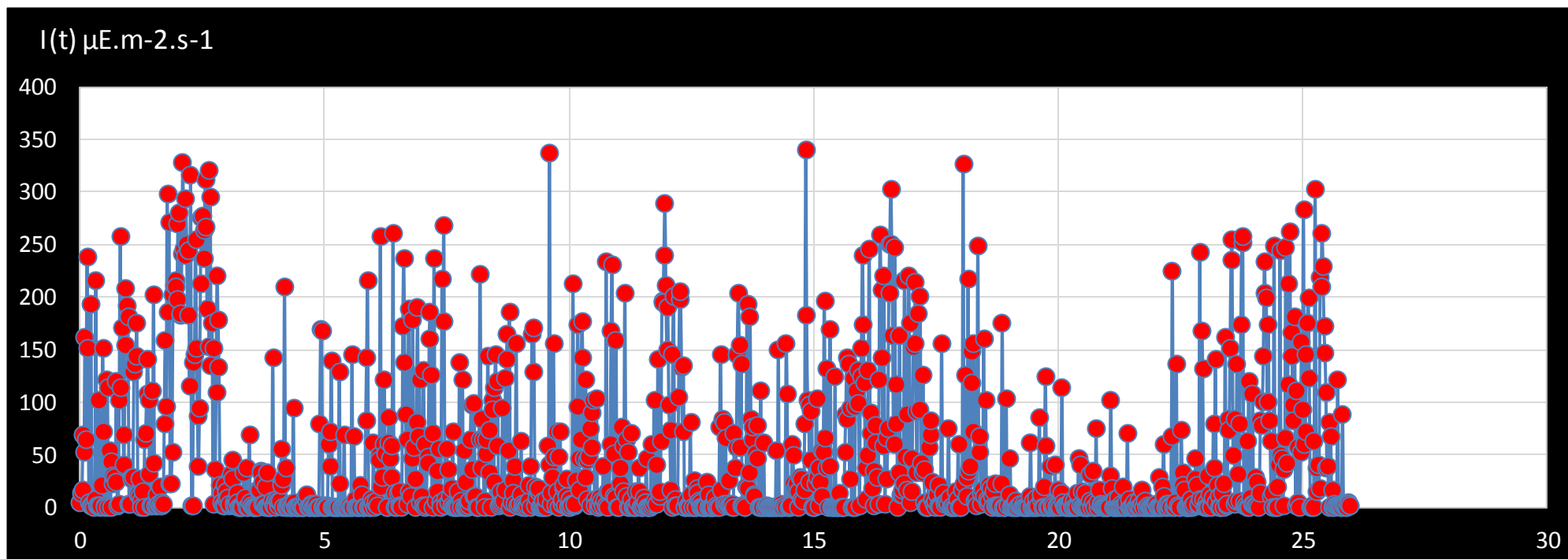
(Evers, 1991)

$$t^j < t < t^{j+1}$$

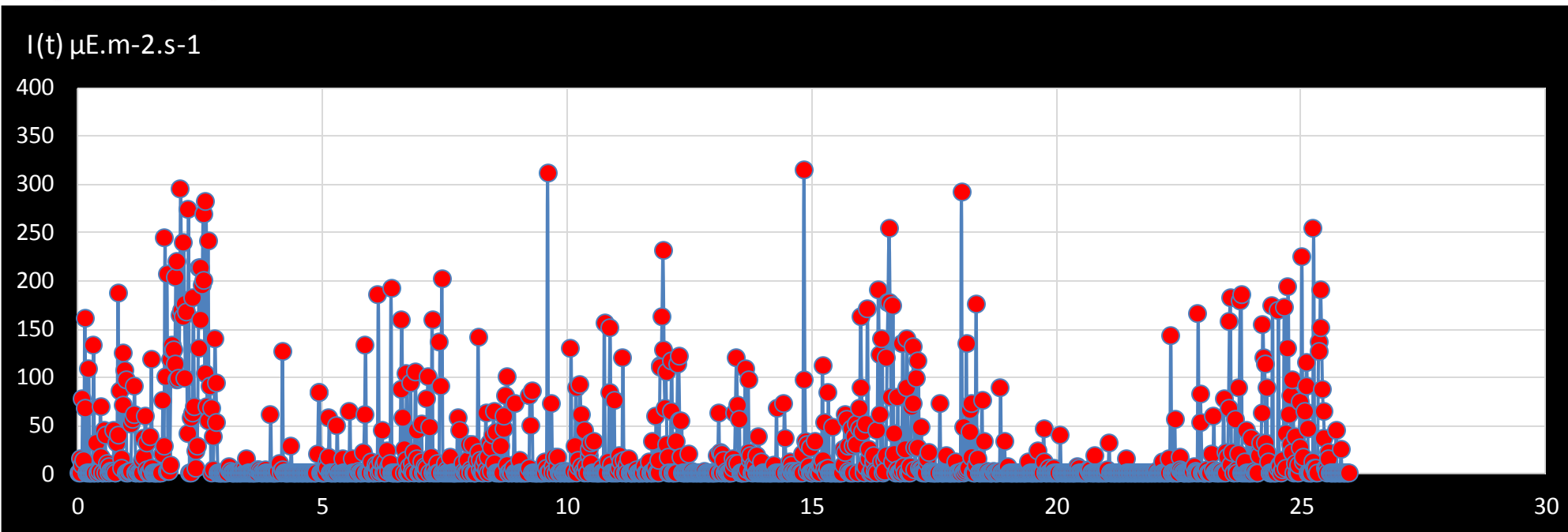
Visualization of typical trajectories of the tracer particle



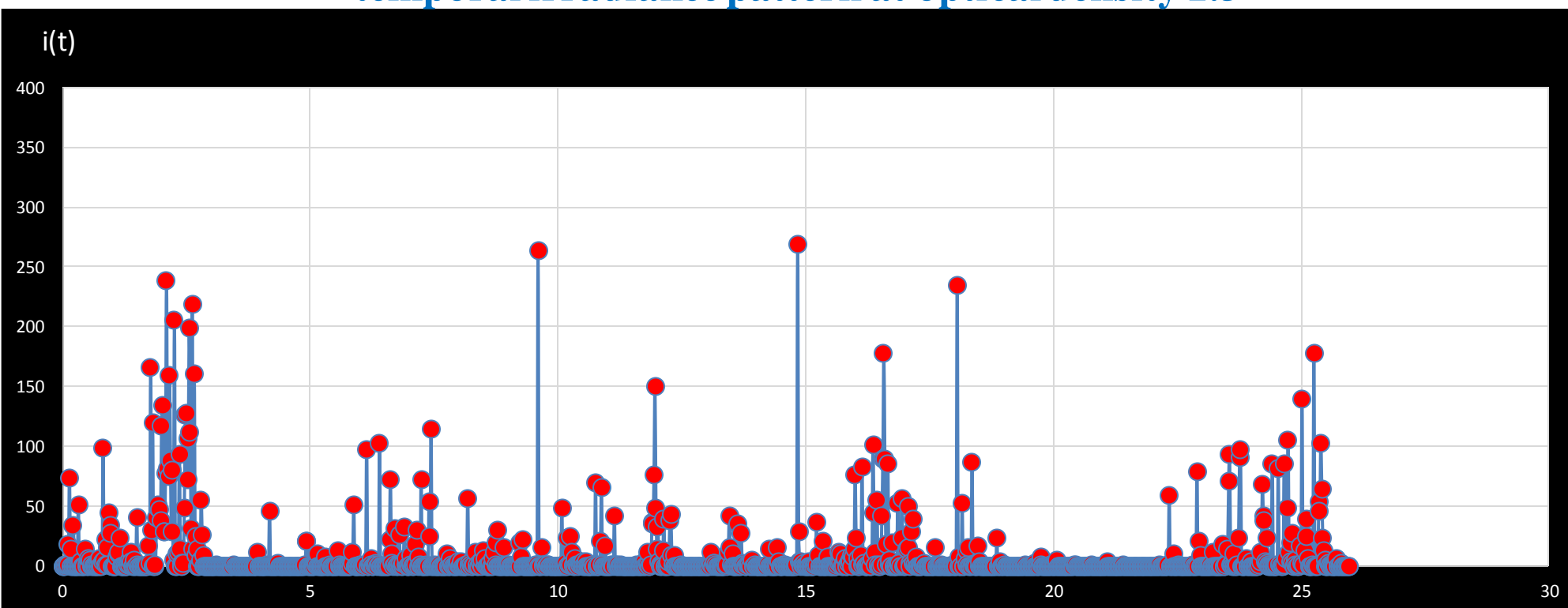
temporal irradiance pattern at optical density 0.0



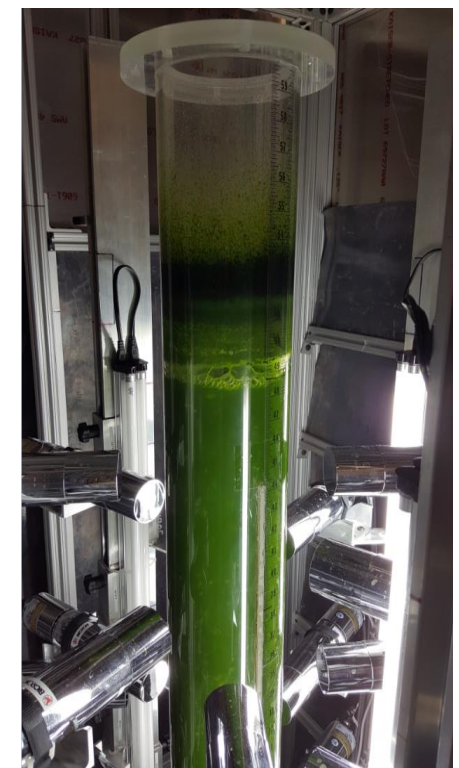
temporal irradiance pattern at optical density 0.8

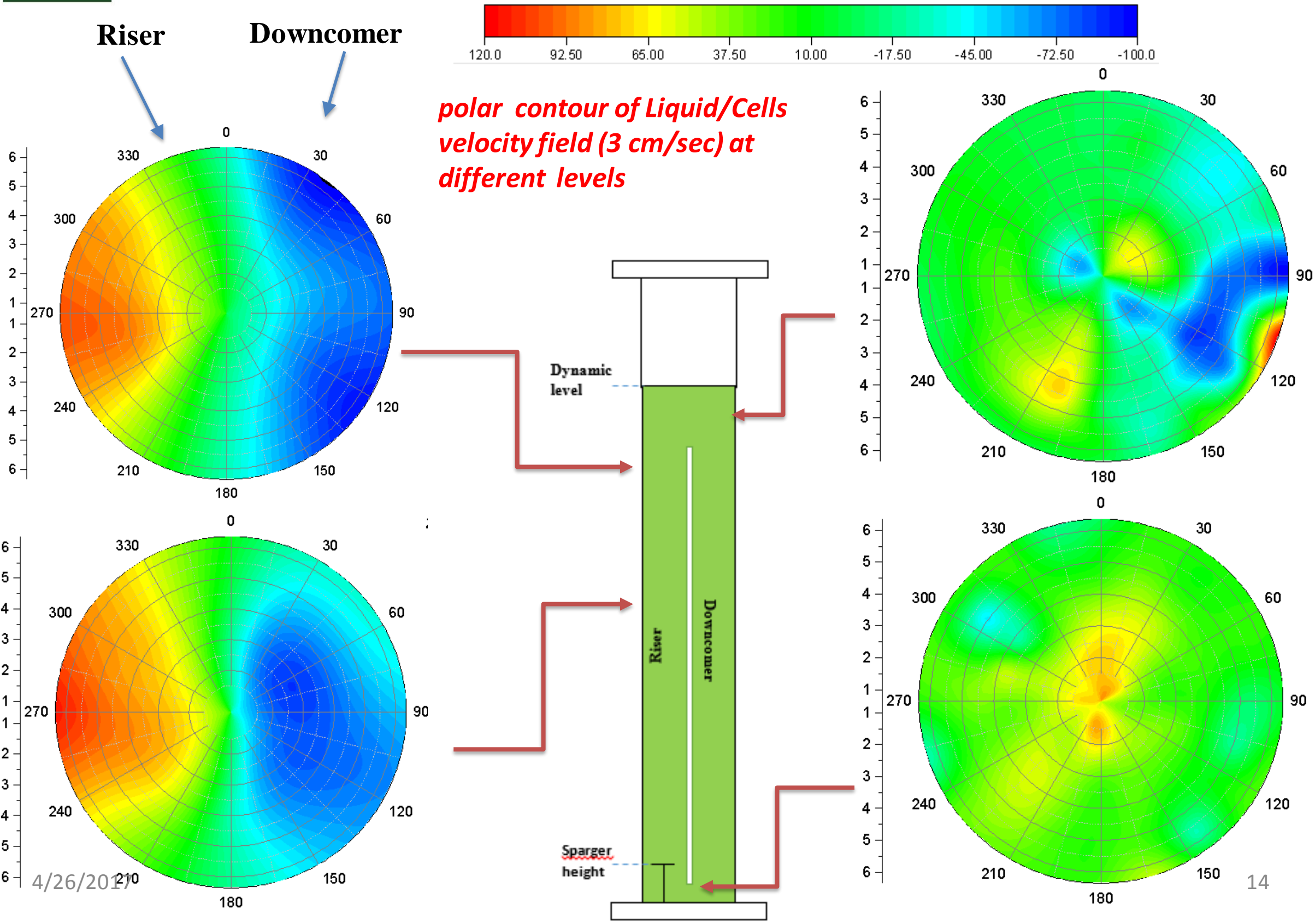


temporal irradiance pattern at optical density 1.3

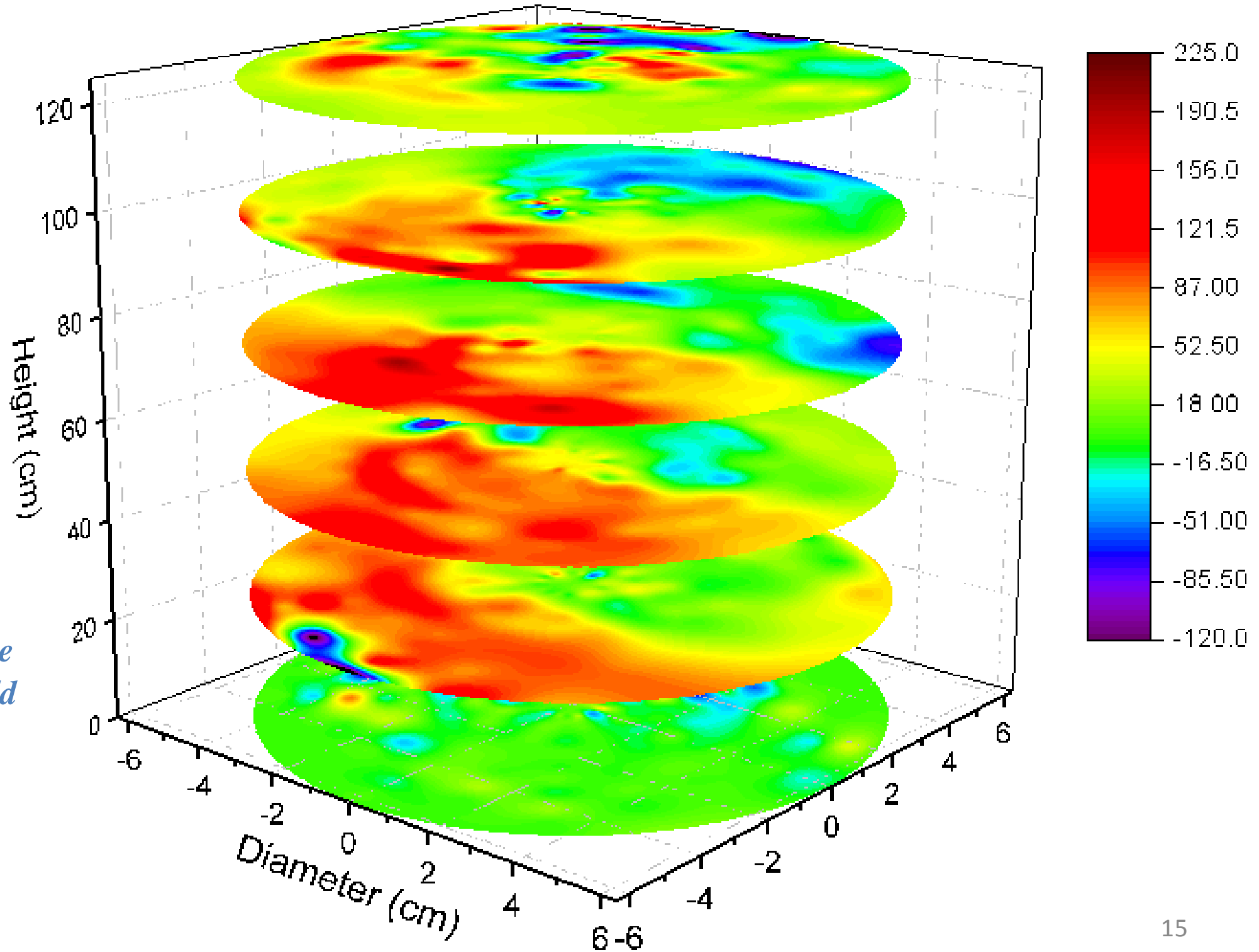


temporal irradiance pattern at optical density 2.0



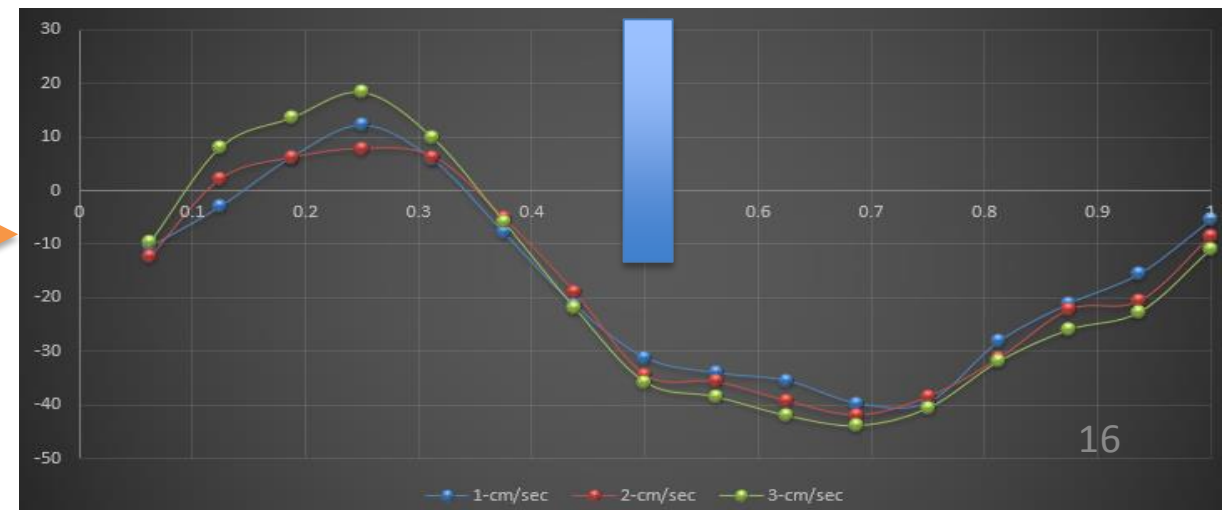
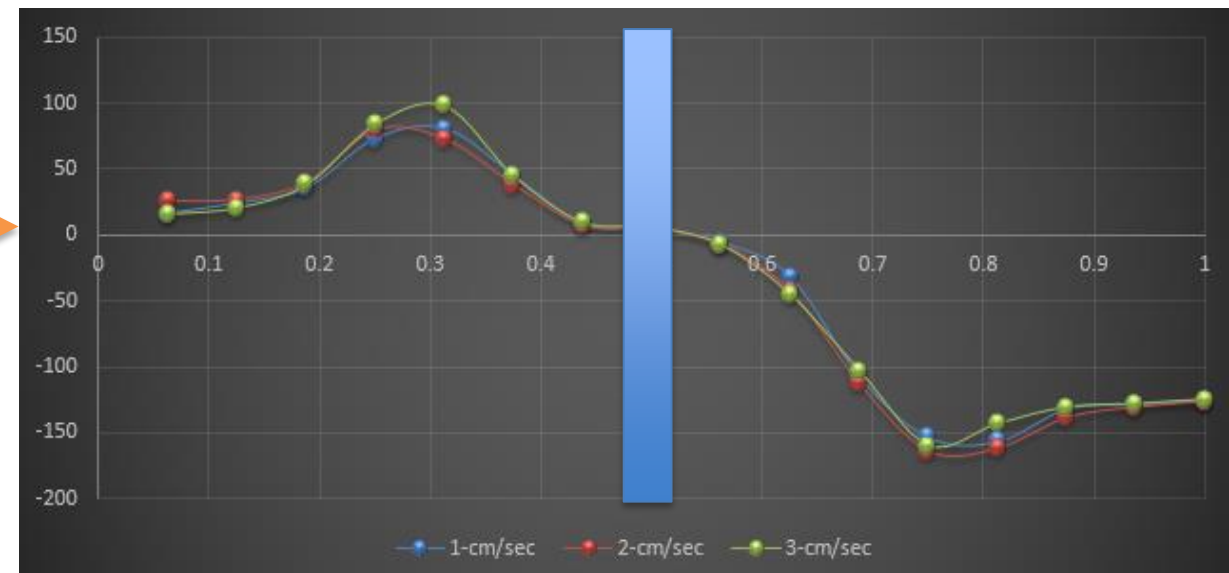
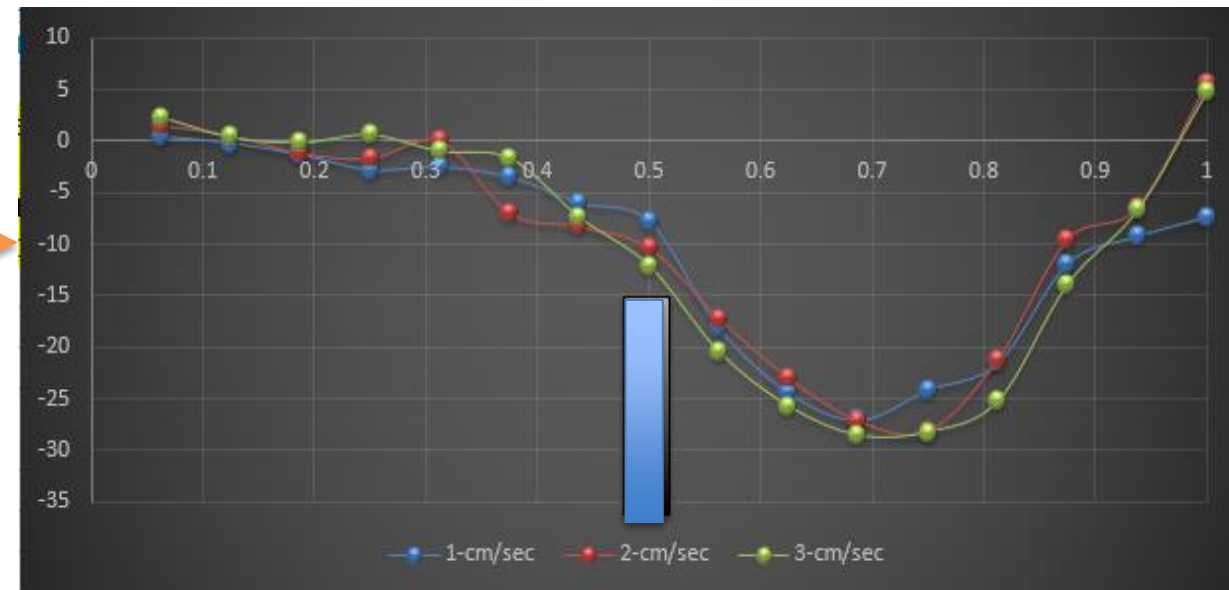
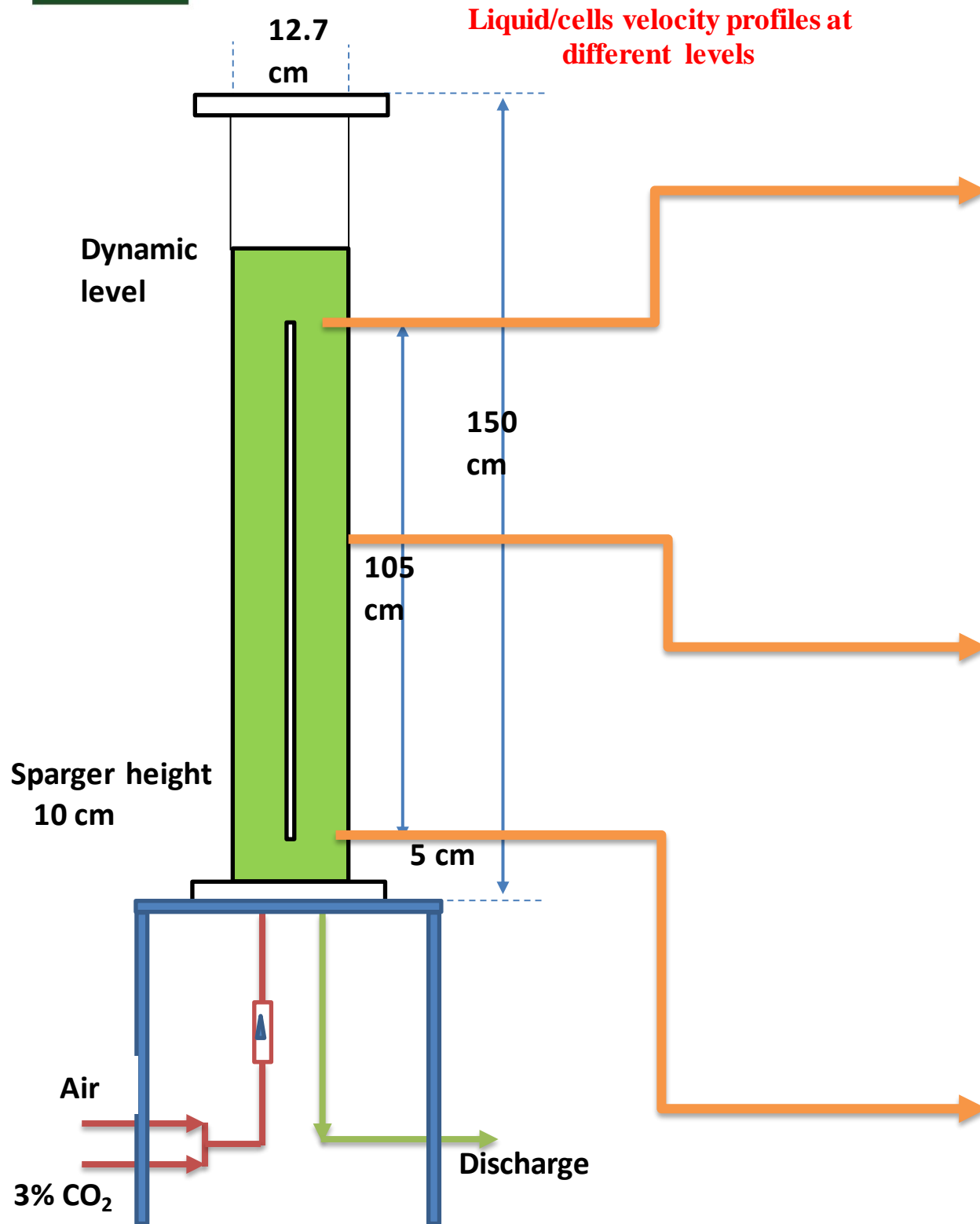


3D visualization of liquid/Cells velocity field in the split airlift photobioreactor



3D Visualization of the liquid/cells velocity field at 3cm/sec

Liquid/cells velocity profiles at different levels



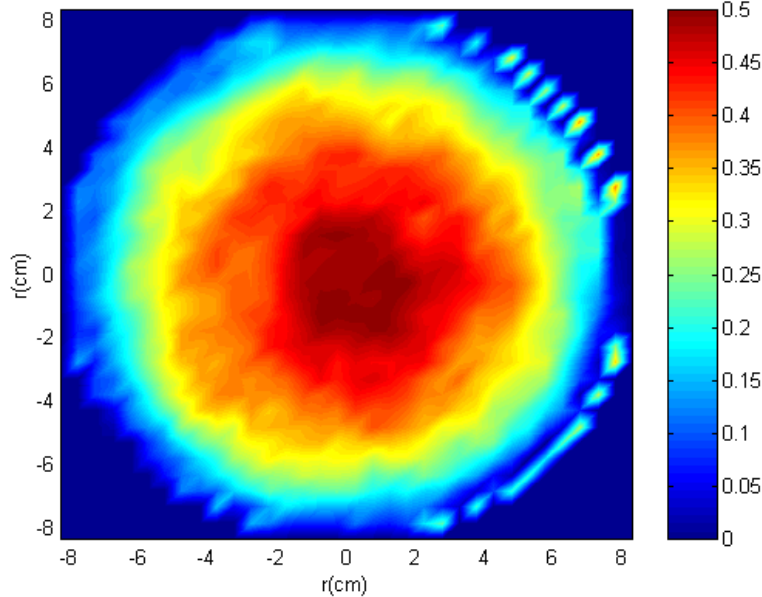
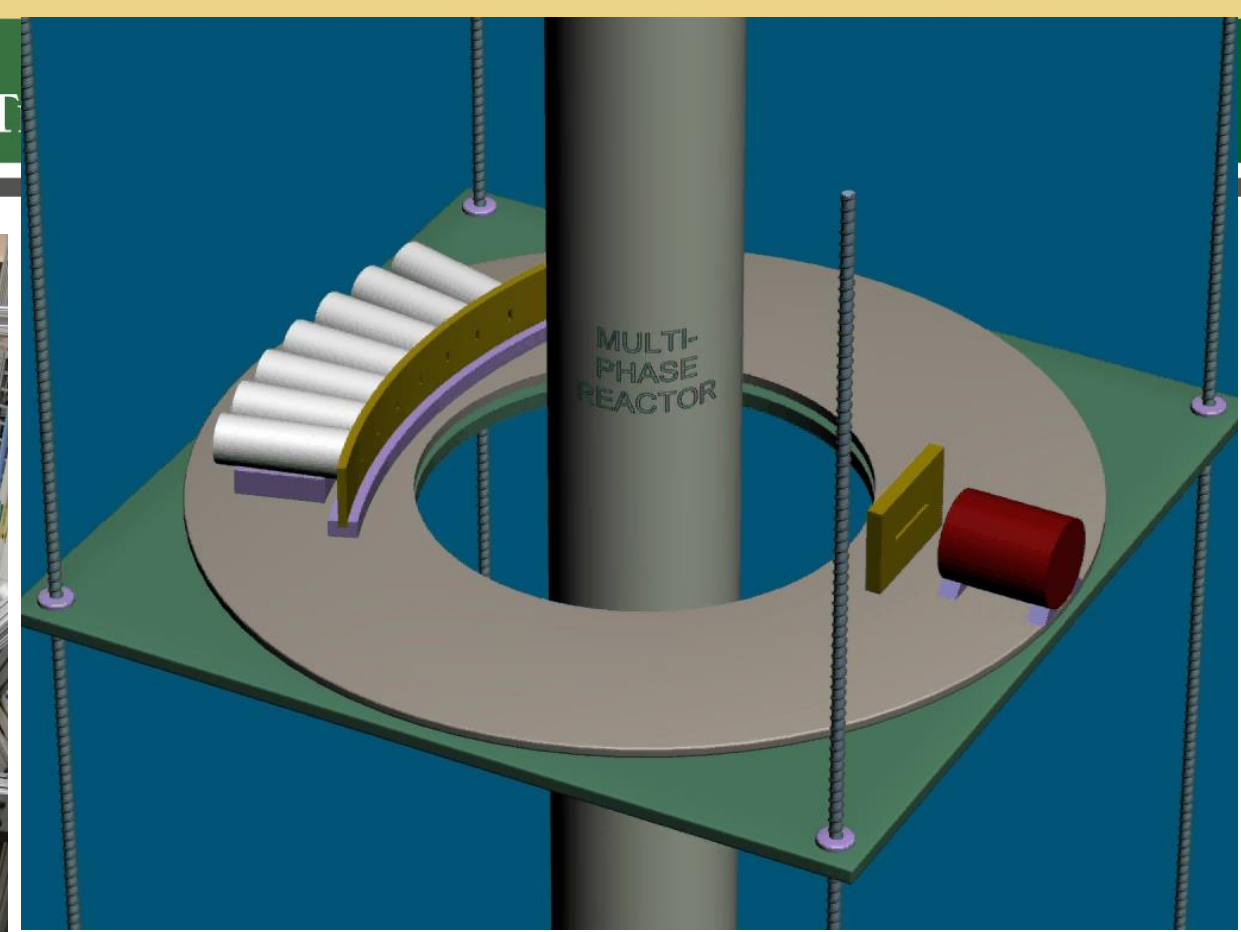
Remarks

- RPT technique provides in-depth knowledge of the cells trajectories/measurements velocity field, Reynolds stress distribution, eddy diffusivity, local and global residence time, and many others parameters.
- The RPT obtained cells' trajectories integrated with irradiance field models provide the local light intensity received by the cells as a function of time and cells' positions (x,y,z) inside the culture of photobioreactor sophisticatedly.
- This enables the implementation of our approach to evaluate in depth the culturing optimization, reactor performance and effects of operating conditions on culturing microalgae to produce reliable design and scale up.
- The obtained knowledge provides valuable benchmark experimental data for evaluation and validation computational fluid dynamics(CFD) in our integrated approach.

Acknowledgements

The authors would like to acknowledge the financial support provided by the Iraqi Ministry of Higher Education & scientific research Iraq and The Iraqi Higher Committee For Education Development in Iraq (HCED), and the fund provided by Missouri S&T and professor Al-Dahhan for the development of the Radioactive Particle Tracking (RPT) technique, the experimental set-up and to perform the experiments.

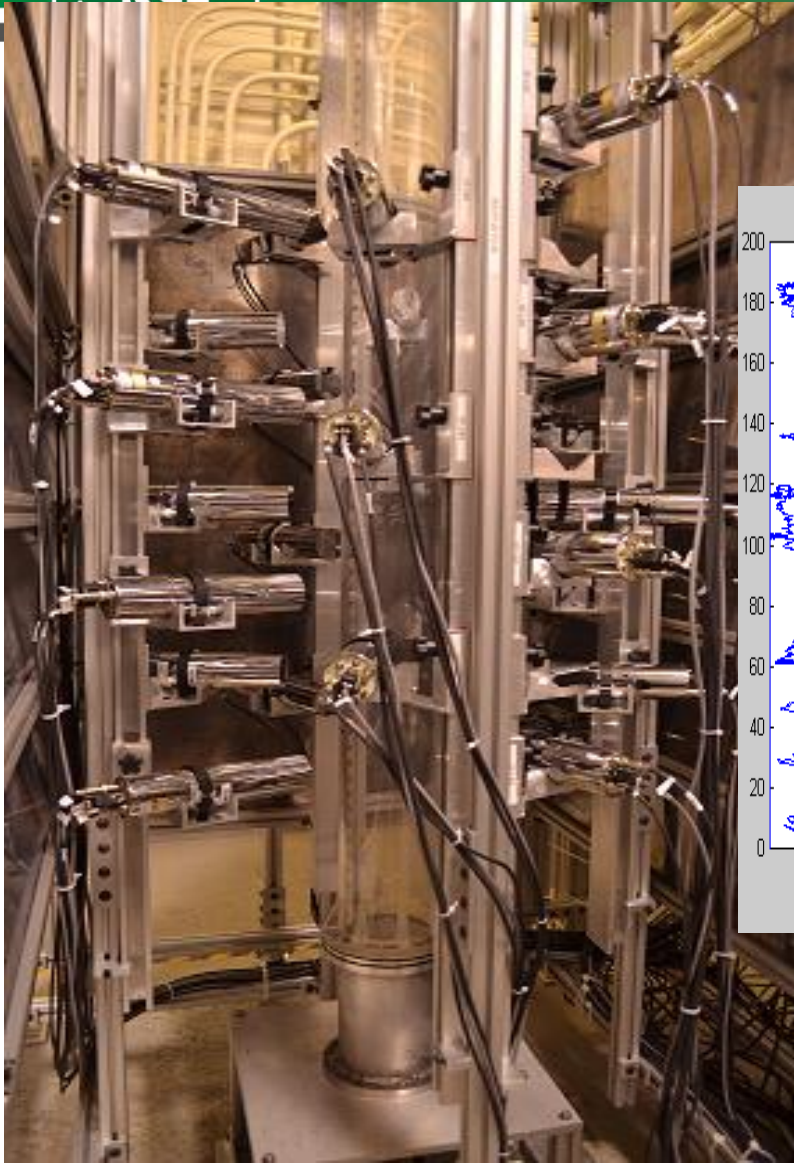
For Phase Distribution Measurement



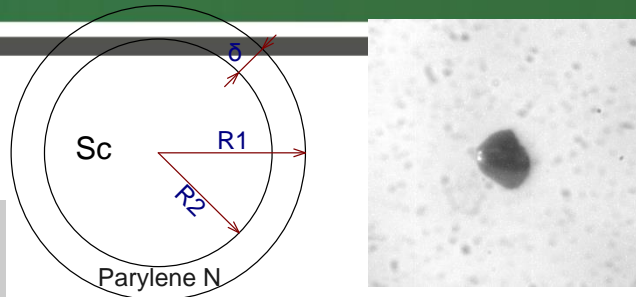
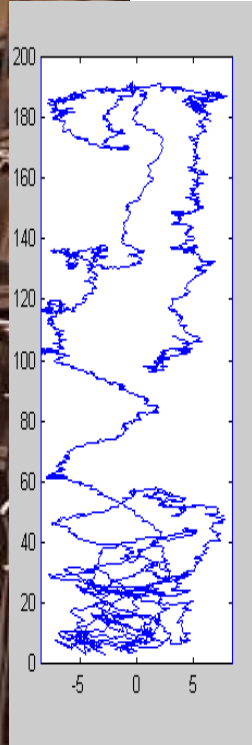
Radioactive Particle Tracking (RPT)



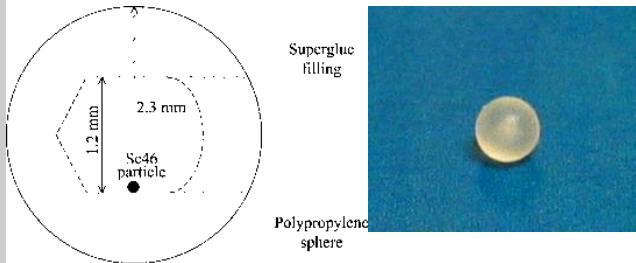
MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY



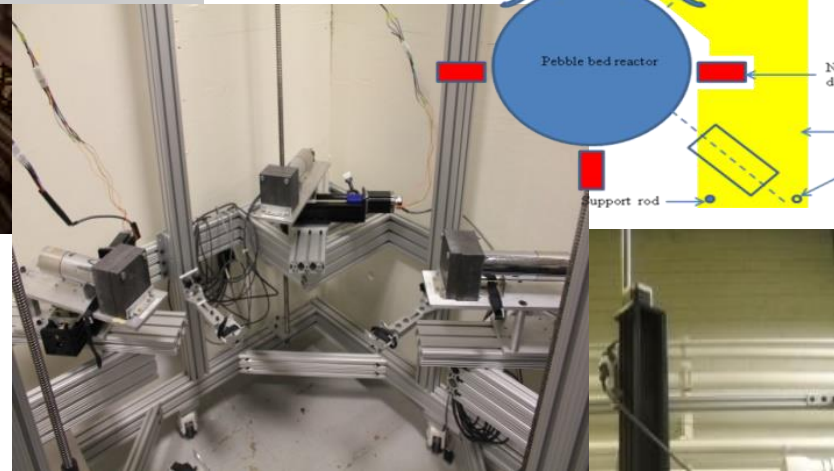
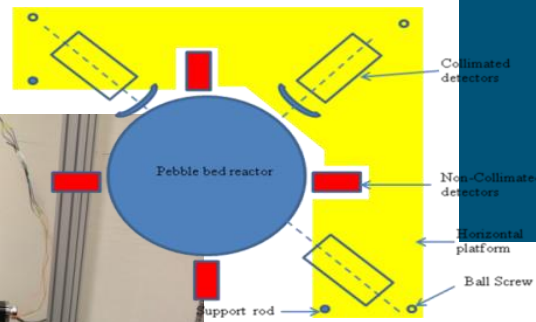
Picture of RPT



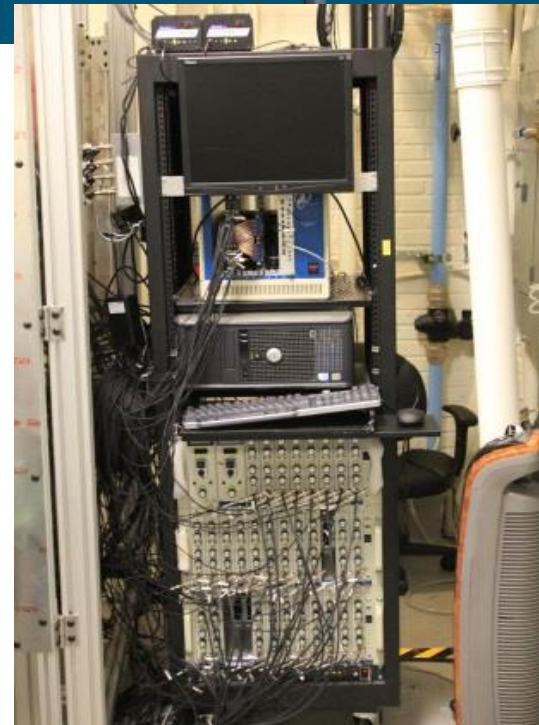
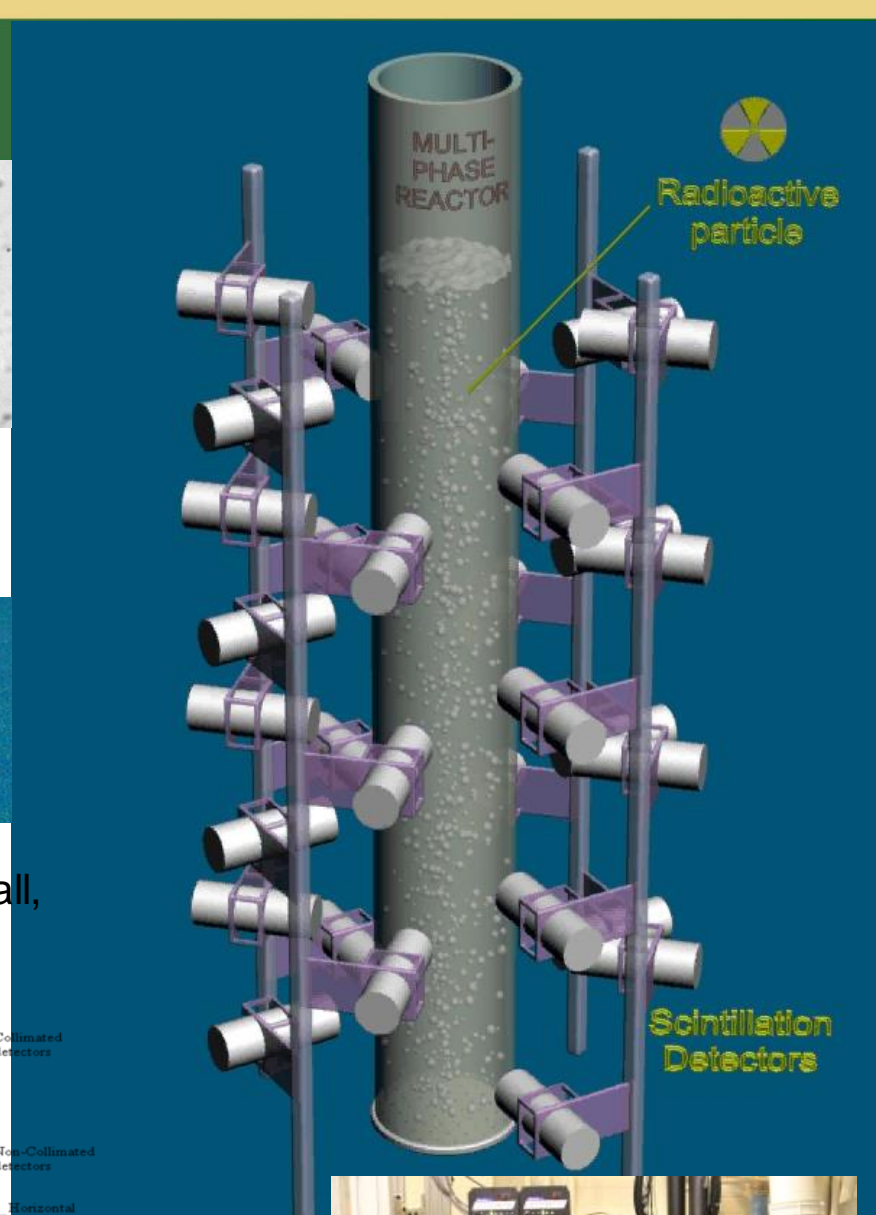
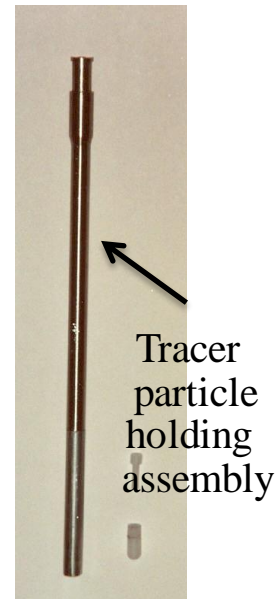
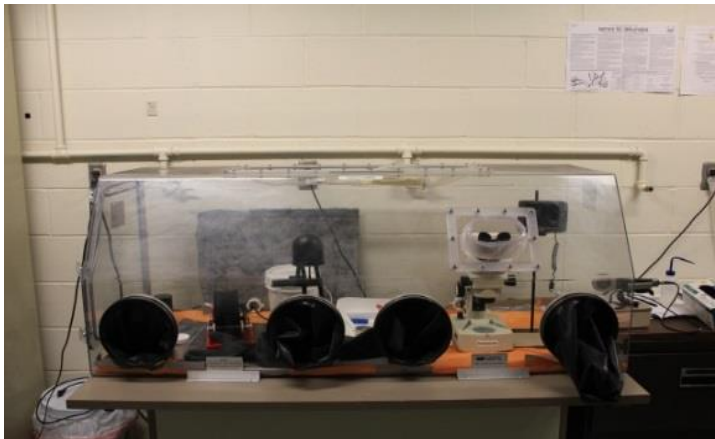
Sc⁴⁶ particle coated with parylene-N, tracking solids



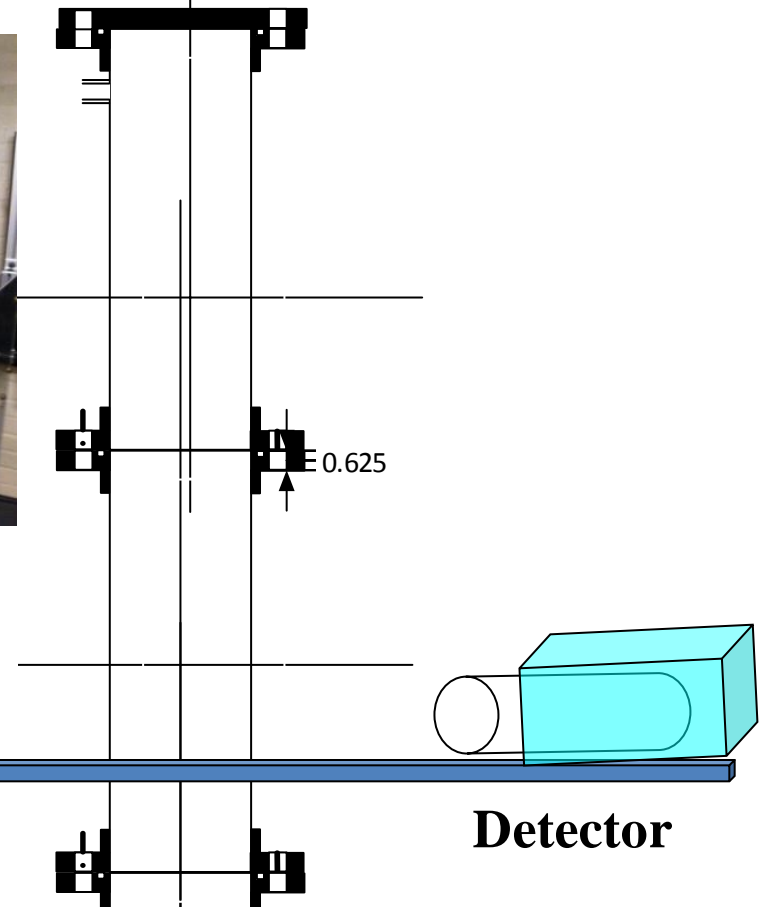
Sc⁴⁶ particle in polypropylene ball, tracking liquid



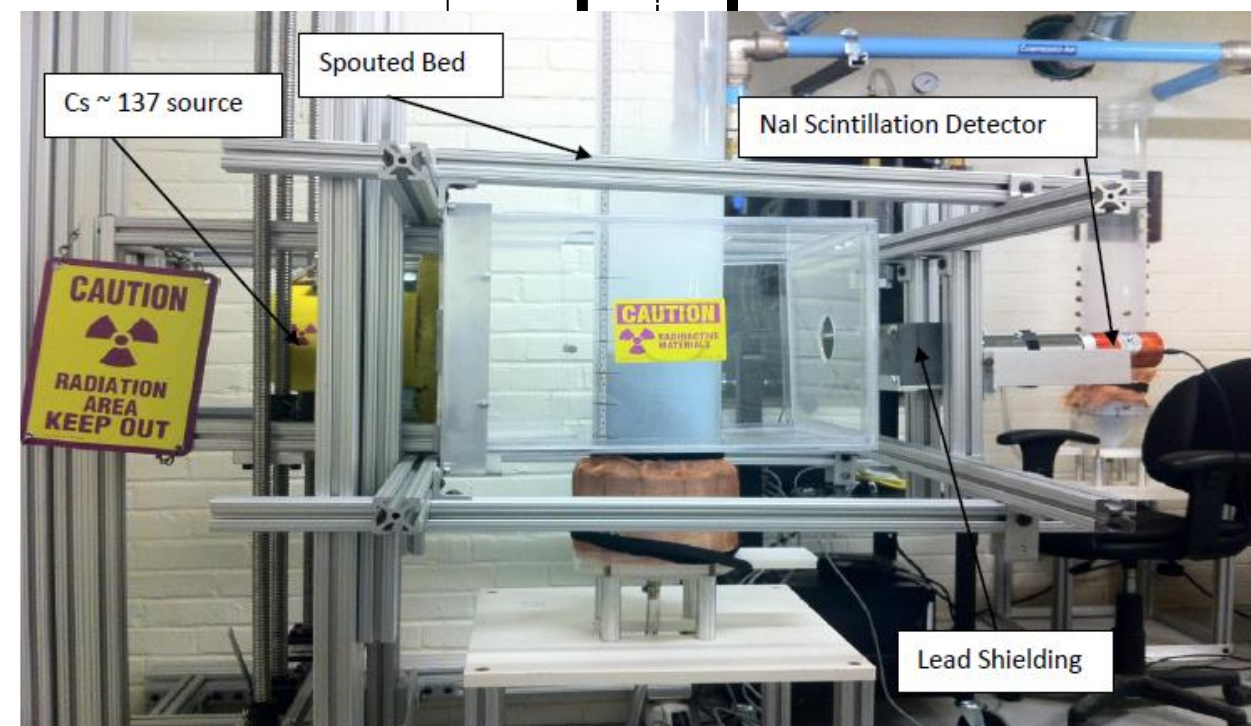
In Situ
Manual
RPT
Calibration



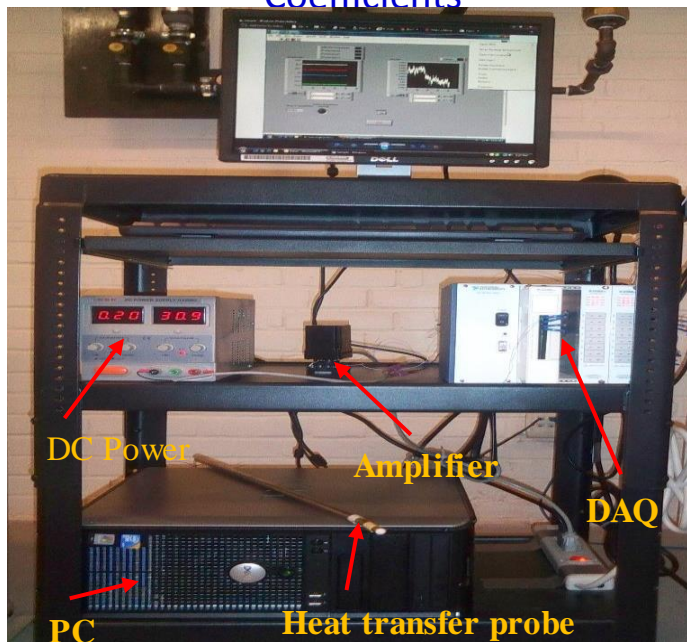
An On-line Technique Using NGD as **Gamma Ray Densitometry (GRD)**



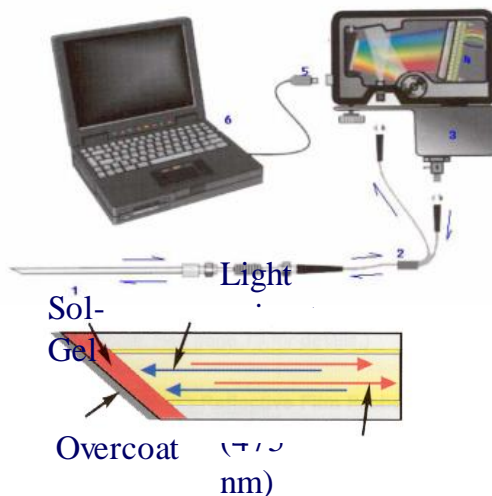
For Pinpointing Flow Pattern (Regime), Radial/Diameter Profile of Phases' Holdups
Mal-distribution identification & Reduced Tomography



Heat Transfer Coefficients

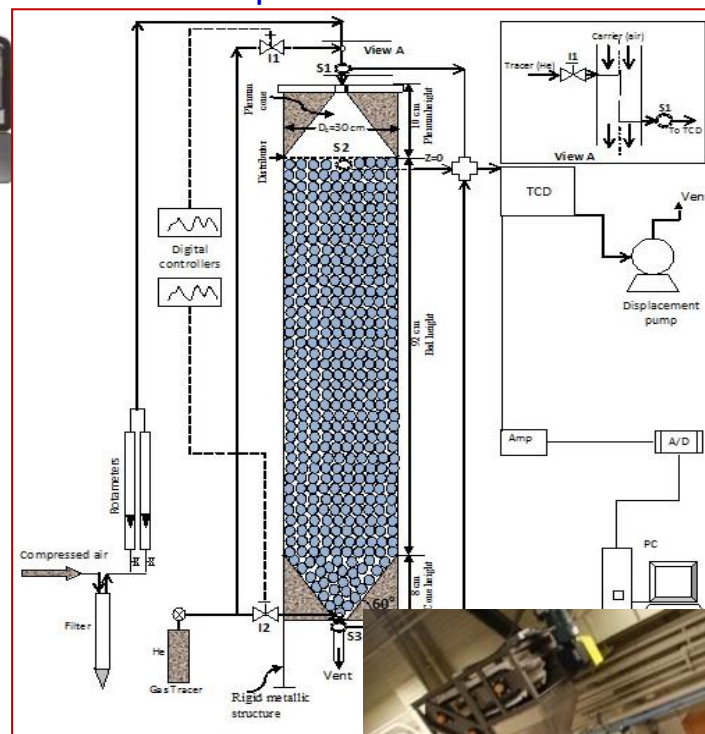


Mass Transfer Probes

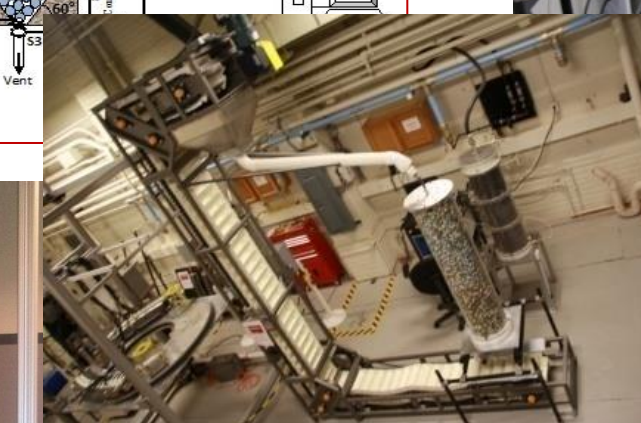
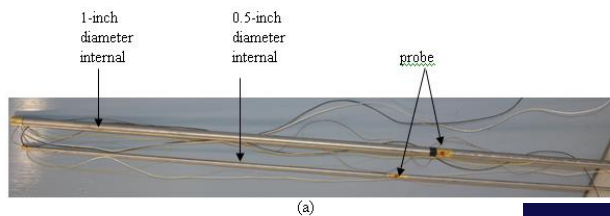
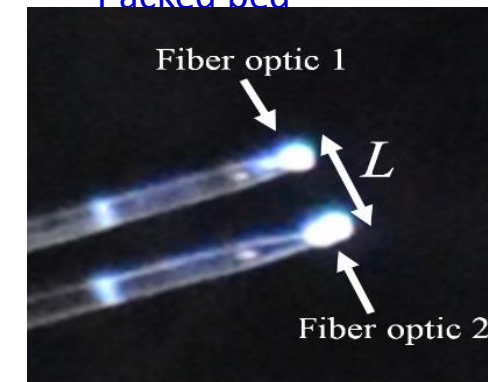


Gas-Solid optical probes

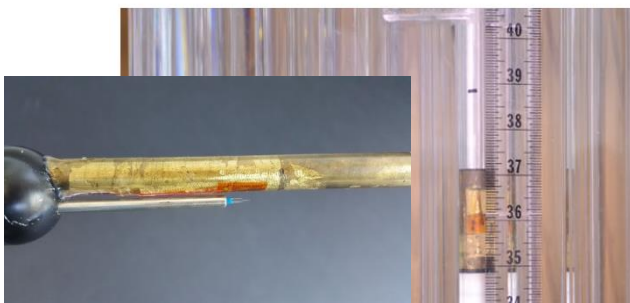
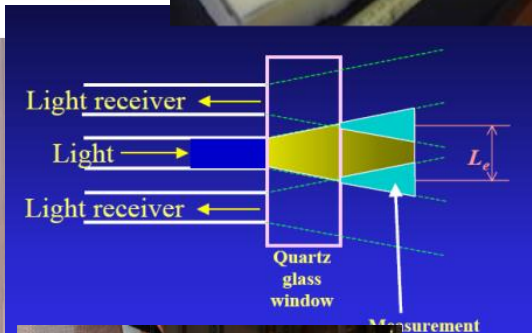
Gas/Liquid Dynamics – Tracer Techniques



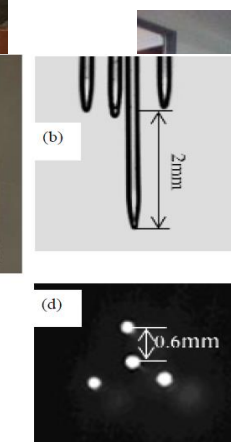
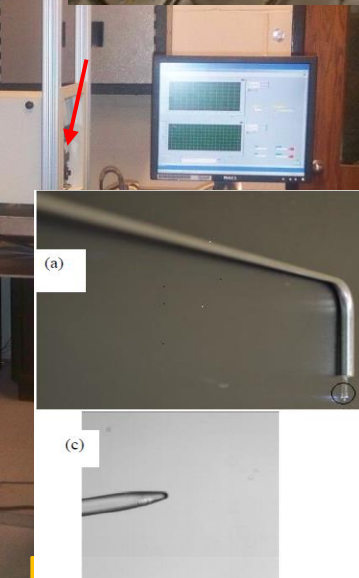
Optical Probes in Packed bed



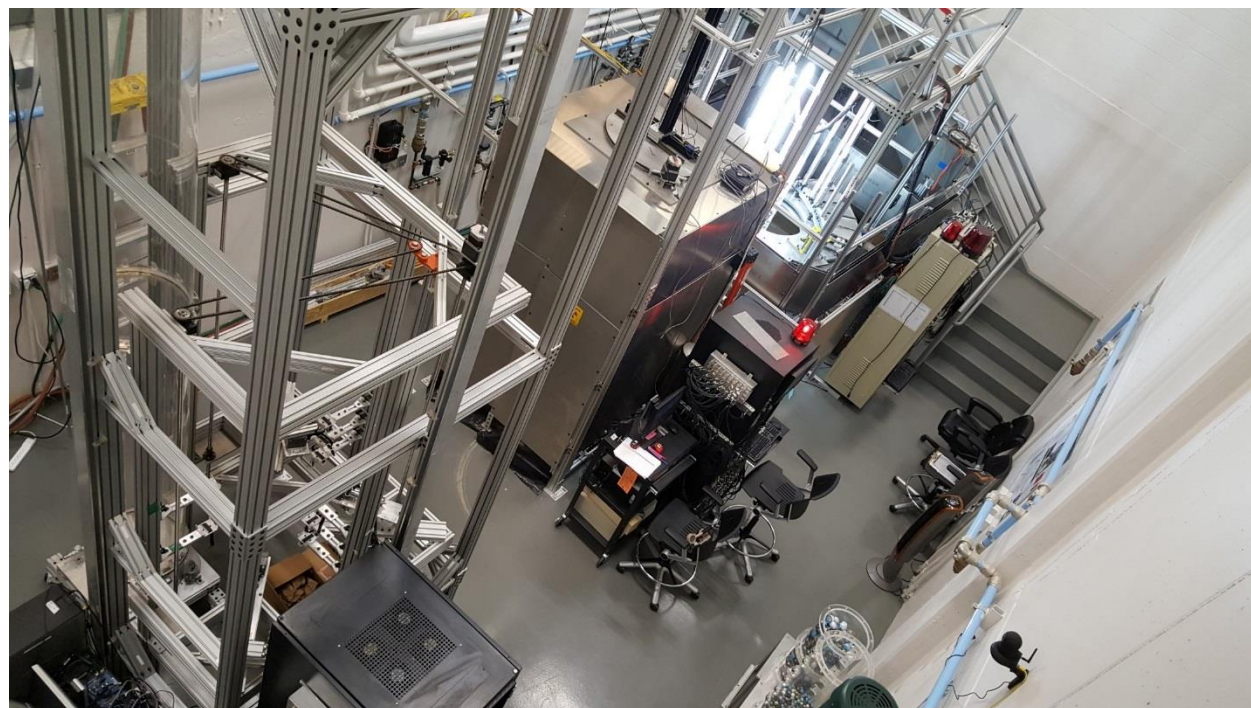
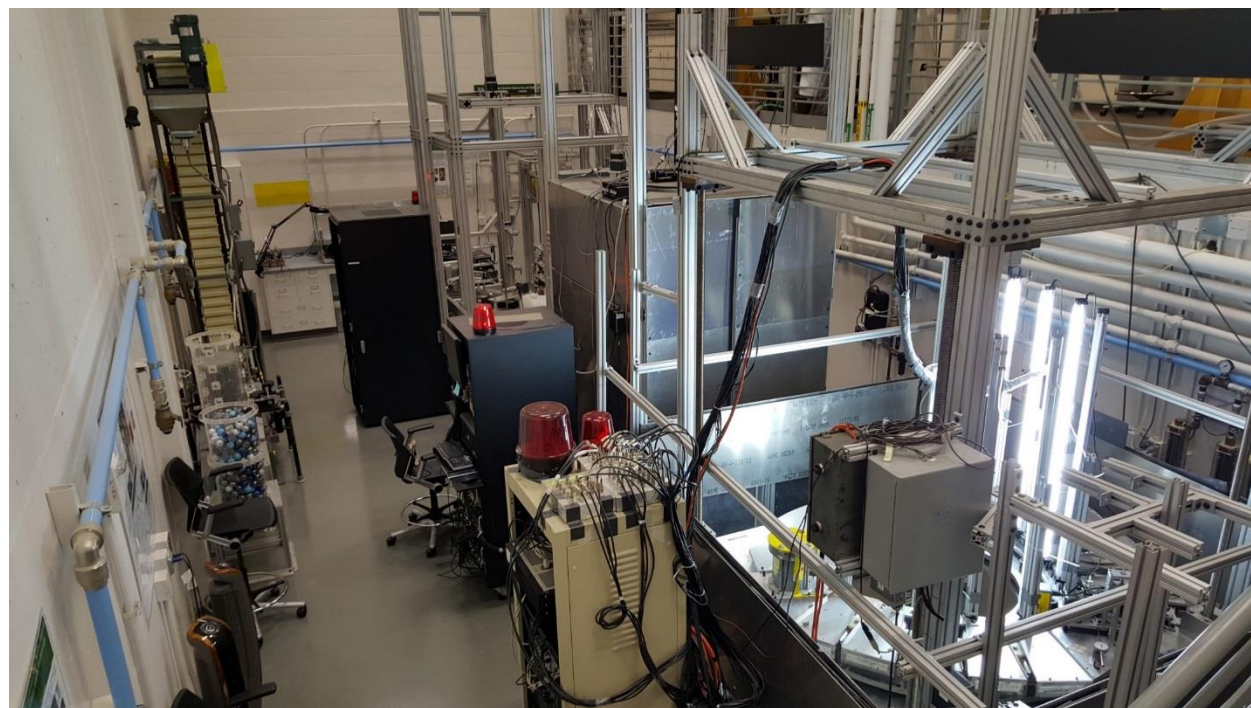
Rigs

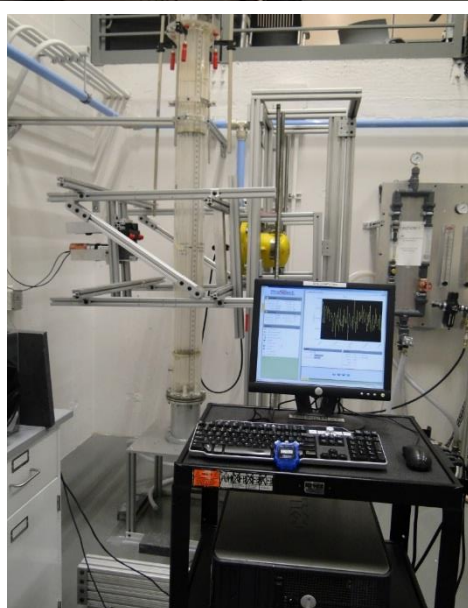
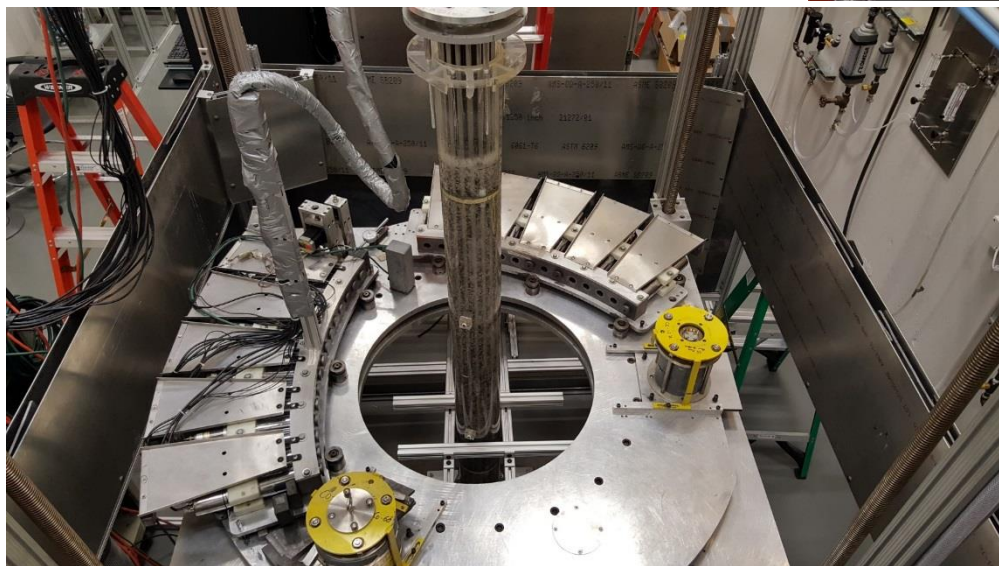
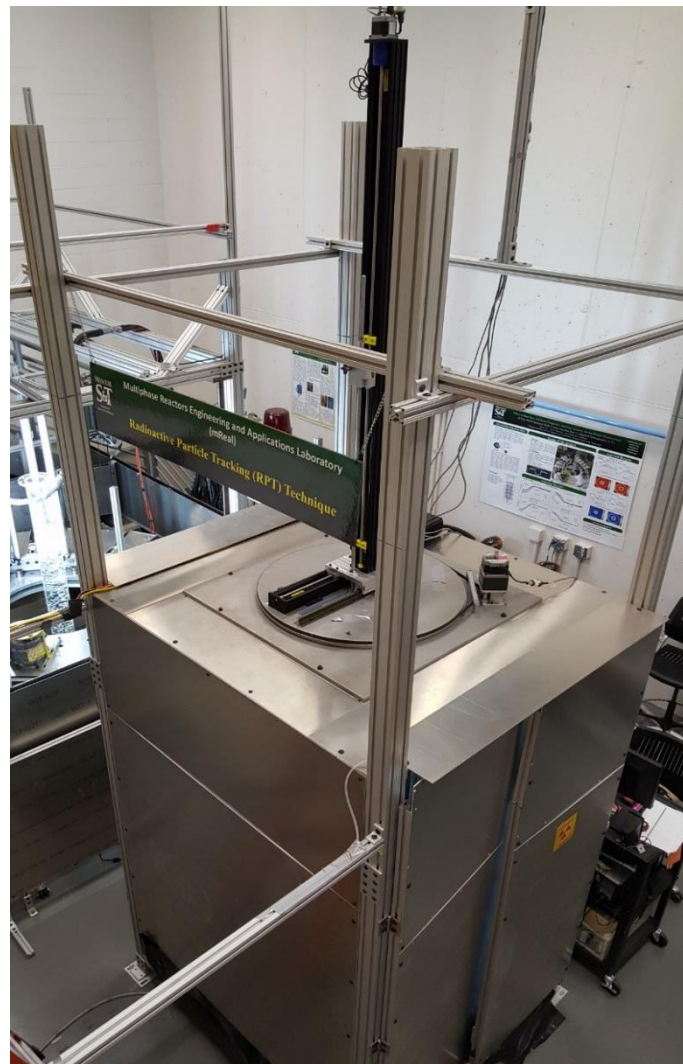
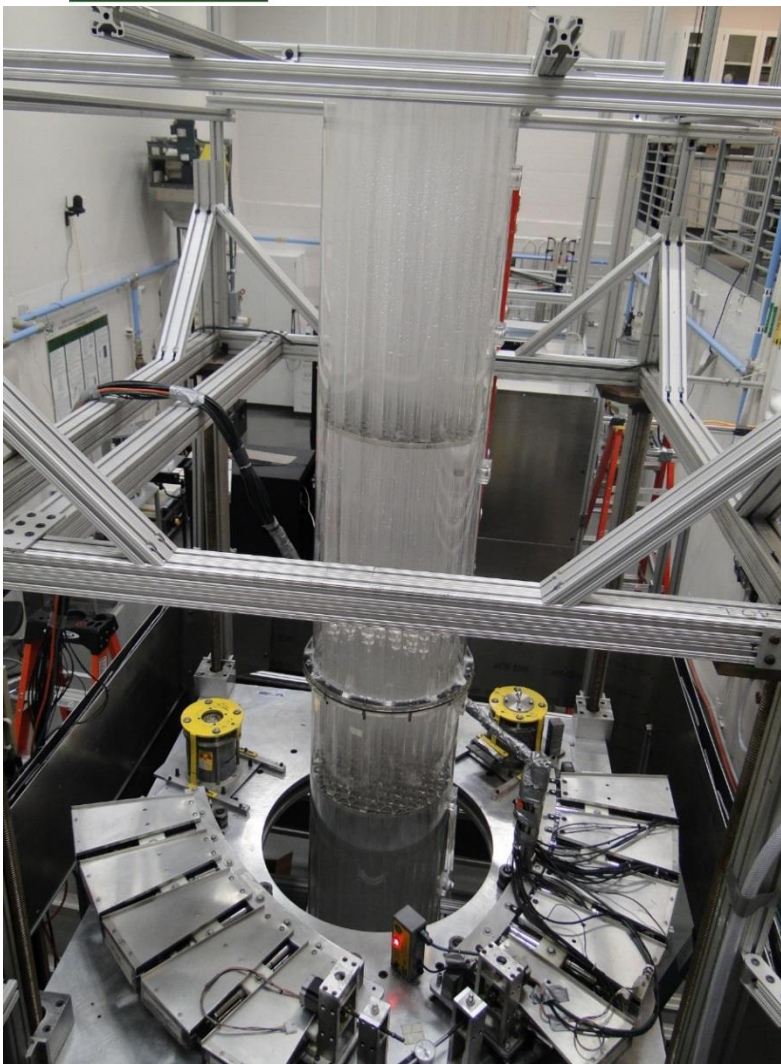


Pressure Transducers



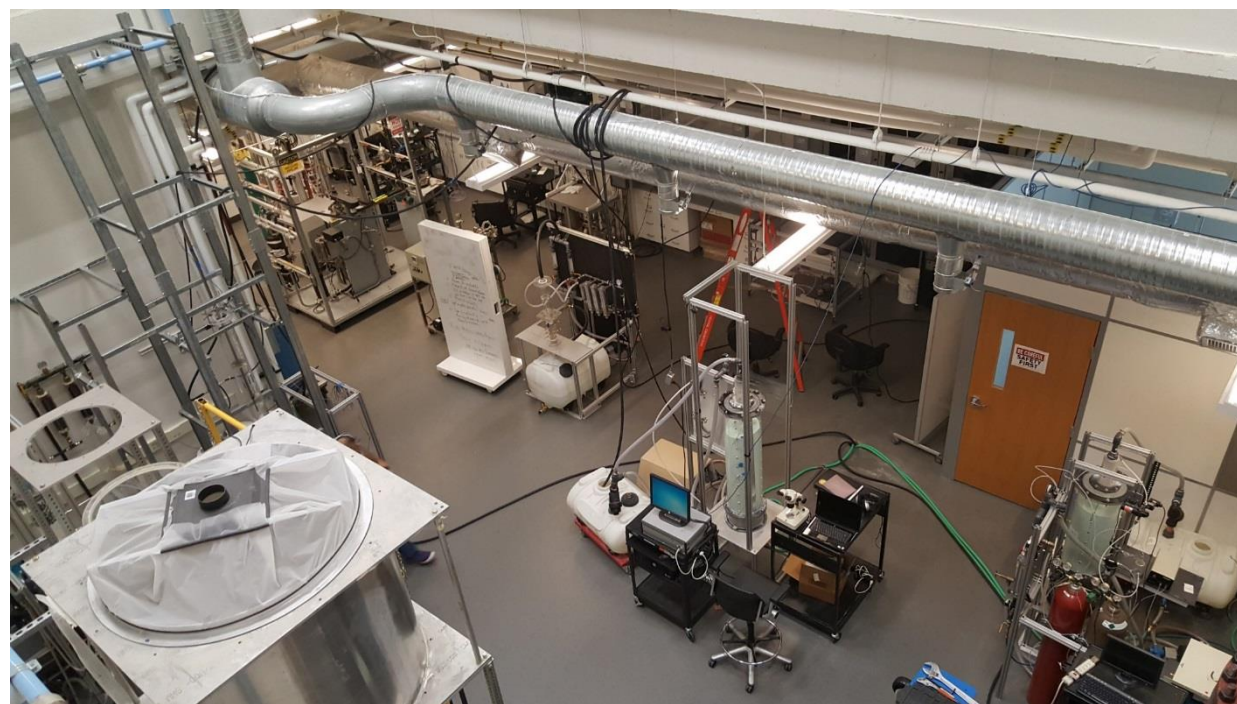
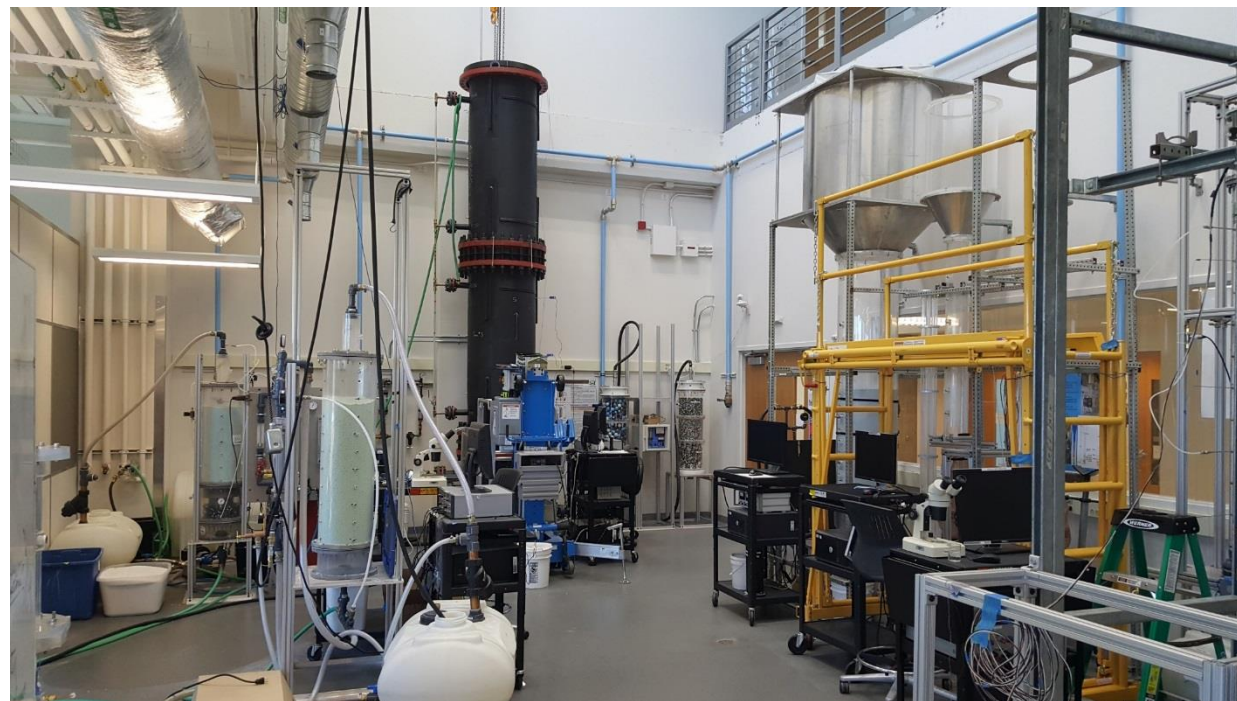
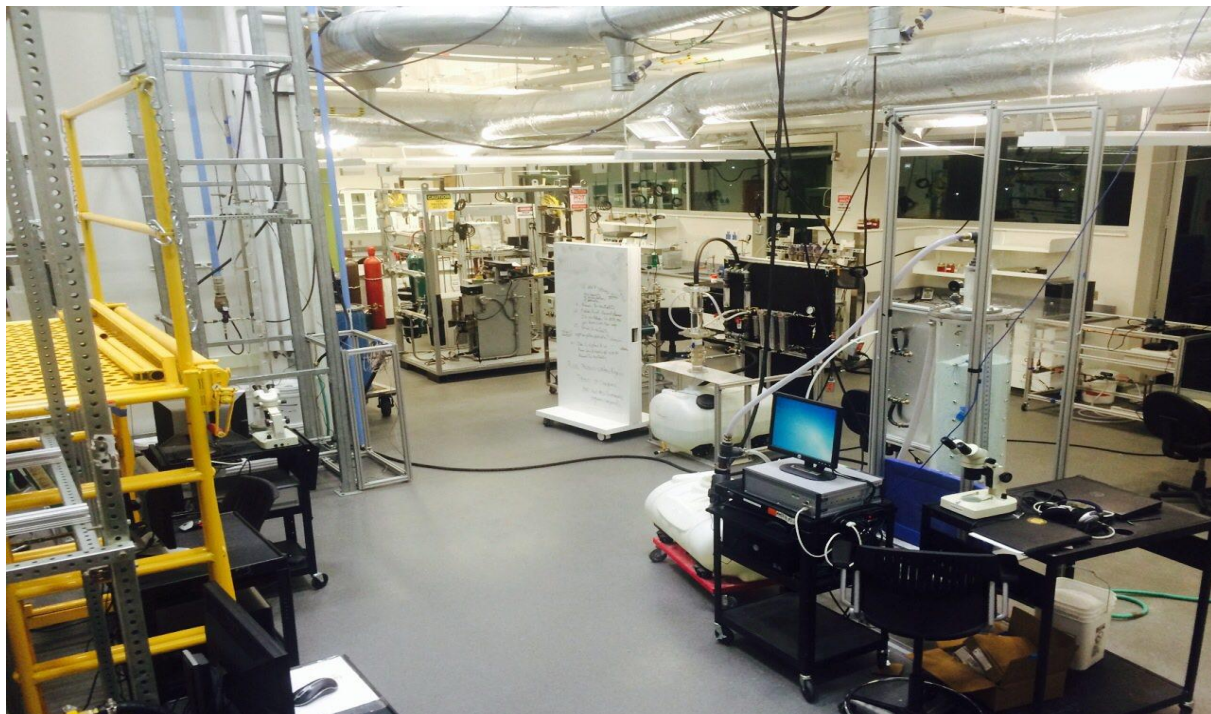
Radioisotope Laboratory for Advancing Industrial Multiphase Processes



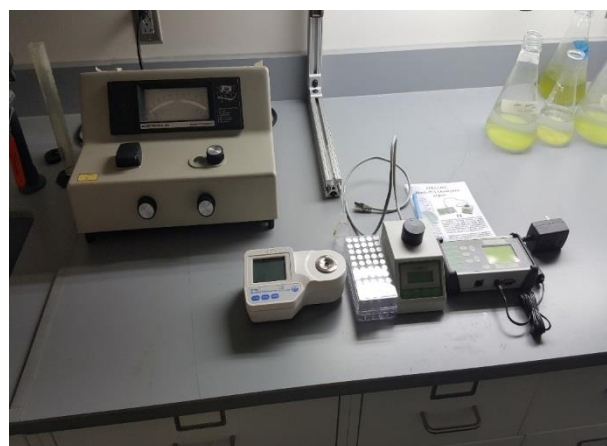


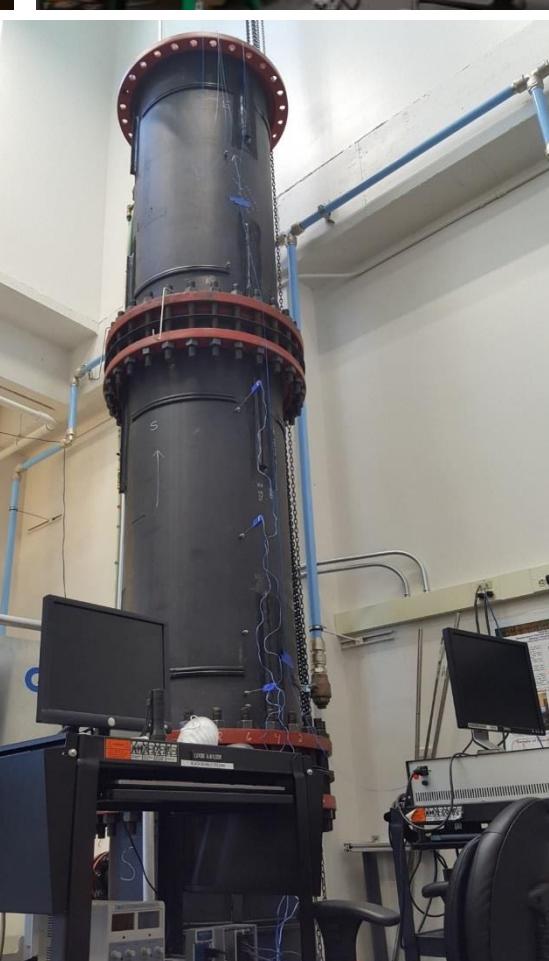
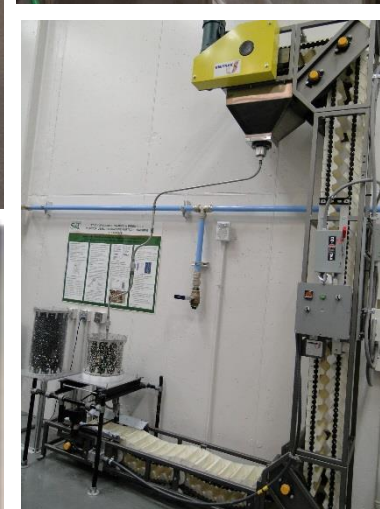
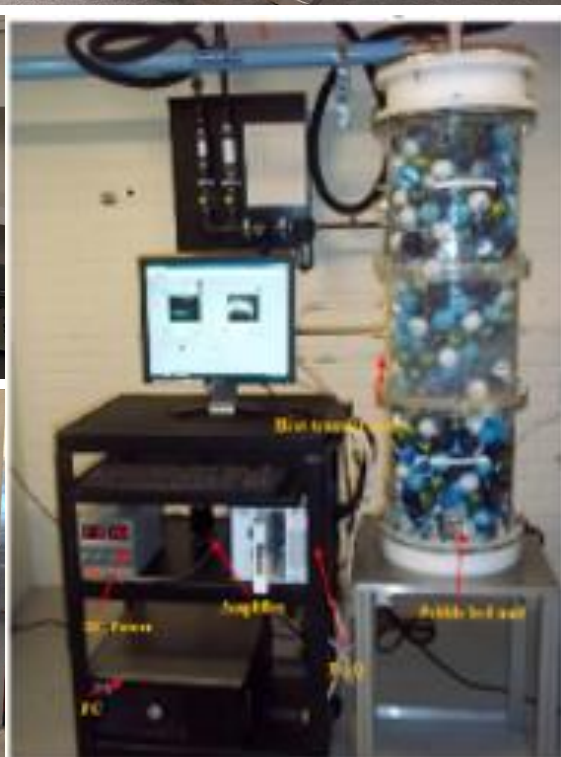
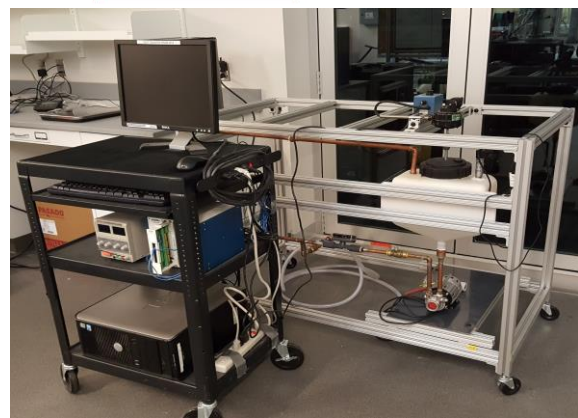
Dual Source Computed Tomography (DSCT) Technique

Non-Radioisotope Laboratory for Advancing Industrial Multiphase Processes



Microalgae Laboratory (Biological Lab)





Thank you

